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MCDONNELL DOUGLAS
CORPORATION

APPLICATION OF SHUTTLE EVA SYSTEMS TO PAYLOADS

FINAL REPORT
CONTRACT NAS 9-14678

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EVA SYSTEMS AND OPERATIONAL MODES DESCRIPTION

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VOLUME I:

EVA SYSTEMS AND OPERATIONAL MODES DESCRIPTION

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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FOREWORD

Numerous experiments have been identified for Shuttle applications ranging from space exposure of various material samples to planetary soil return missions including a search for the "edge" of the universe. Payload systems to support the numerous experiment operations are being developed with emphasis on providing the greatest scientific return per dollar invested in equipment and transportation. Servicing, repairing, and refurbishing payloads are some of the more significant measures that can be applied either through ground based or orbital operations.

Since manned extravehicular activity (EVA) is a qualified, prime candidate for economically conducting on-orbit payload support functions, this study was designed to assist in correlating experiment and payload requirements with EVA capabilities, systems and operational modes. The study was sponsored by the Bioengineering Division, Life Sciences Office of NASA Headquarters, Dr. Stanley Deutsch, Director. The work was monitored under the technical direction of Mr. John H. Covington, Crew Procedures Division, Flight Operations Directorate of the Lyndon B. Johnson Space Center, Houston, Texas. The Contracting Officer was Mr. Thomas R. McPhillips, Program Procurement Division, JSC.

Major objectives of the study were as follows: (1) to develop a comprehensive description of the Space Shuttle baseline EVA systems including candidate EVA-assisted operational modes; (2) identify and select candidate payload tasks across representative payloads for EVA application; and (3) develop payload EVA task completion plans including preliminary EVA operational procedures and timelines. The study was performed over a twelve-month period beginning June 1975.

The final report for the contract is presented in two volumes:

SPACE SHUTTLE EVA

MDC W0014
2 JUNE 1976

Volume I: EVA Systems and Operational Modes Description

Volume II: Payload EVA Task Completion Plans

This document (Volume I) provides descriptions of the EVA systems baselined for the Shuttle Program and contains a compendium of data on available EVA operational modes for payload and Orbiter servicing. Operational concepts and techniques to accomplish representative EVA payload tasks are proposed.

ACKNOWLEDGEMENTS

The NASA Technical Monitor for the study was Mr. John H. Covington, Crew Training and Procedures Division, Flight Operations Directorate, Johnson Space Center, Houston, Texas. Contract monitoring and technical assistance were provided by Mr. David C. Schultz, Chief, Crew Systems Branch, and Mr. Raymond G. Zedekar, Chief, EVA Systems Section of the Crew Training and Procedures Division. Special appreciation is expressed to Dr. Stanley Deutsch, Director, Bioengineering Division, Office of Life Sciences, NASA Headquarters, for his efforts in arranging for the conduct of the study.

Significant contributions in obtaining quantitative data and technical information were provided by personnel within the NASA Johnson Space Center. Sincere appreciation is due Mr. Jack C. Heberlig/LP, Mr. Ted H. Skopinski/LP, Mr. Stewart L. Davis/LO, Mr. Robert L. Frost/LP, Mrs. Jeri W. Brown/EW5, Mr. Jerry R. Goodman/EK3, Dr. Karl G. Henize/TE, and Mr. Gary D. Meester/LP.

The contractor Principal Investigator for the study was Mr. Nelson E. Brown, Study Manager, McDonnell Douglas Technical Services Company, Houston Astronautics Division, McDonnell Douglas Corporation. Principal contributors within McDonnell Douglas were Mr. John F. Schuessler and Mr. William L. Yeakey.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ASMU	Automatically Stabilized Maneuvering Unit
BTU/hr	British Thermal Units per hour
CCA	Communications Carrier Assembly
CCC	Contamination Control Cartridge
CCTV	Closed Circuit Television
C. G.	Center of Gravity
Cm, cm	Centimeter
CSD	Crew Systems Division
C&W	Caution and Warning
DCM	Displays and Controls Module
dia	Diameter
ECLSS	Environmental Control/Life Support System
EEH	EMU Electrical Harness
EMU	Extravehicular Mobility Unit
EOS	Earth Observatory Satellite
EV	Extravehicular
EVA	Extravehicular Activity
EVC	Extravehicular Communication
EVCS	Extravehicular Communication System
EVVA	Extravehicular Visor Assembly
FSS	Flight Support Station
ft	Foot
gm	Gram
gm-Cal	Gram-Calorie
GN_2	Gaseous Nitrogen
GO_2	Gaseous Oxygen
HHMU	Hand Held Maneuvering Unit
HUT	Hard Upper Torso
IDB	Insuit Drink Bag
in	Inch

SPACE SHUTTLE EVA

ACRONYMS AND ABBREVIATIONS (Continued)

IR	Infrared
IVA	Intravehicular Activity
JSC	Johnson Space Center
kg	Kilogram
kg/cm^2	Kilogram per square centimeter
lb	Pound
lbf	Pound force
LCG	Liquid Cooling Garment
LSS	Life Support System
LST	Large Space Telescope
M, m	Meter
Max	Maximum
MDTSCO	McDonnell Douglas Technical Services Company, Inc.
mm	Millimeter
mmHg	Millimeters Mercury
MMU	Manned Maneuvering Unit
N	Newton
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
N-m	Newton-Meter
O_2	Oxygen
OMS	Orbital Maneuvering System
OWS	Orbital Workshop
PAM	Pulse Amplitude Modulation
PIDA	Payload Installation Deployment Aids
PLSS	Portable Life Support System
POS	Portable Oxygen System
PRS	Personnel Rescue System
psia	Pounds per square inch absolute
PSS	Payload Specialist's Station
RMS	Remote Manipulator System

ACRONYMS AND ABBREVIATIONS (Continued)

SCU	Service and Cooling Umbilical
SOP	Secondary Oxygen Pack
SOW	Statement of Work
SSA	Space Suit Assembly
STS	Space Transportation System
TBD	To Be Determined
TPS	Thermal Protection System
TV	Television
UCD	Urine Collection Device
UV	Ultraviolet
WIF	Water Immersion Facility
^{o}C	Degrees Centigrade
^{o}F	Degrees Farenheit
ΔV	Delta Velocity

SECTION 1.0 INTRODUCTION

A major objective of this Shuttle Extravehicular Activity (EVA) study was to present information to the Shuttle payload community on the capabilities of the Orbiter EVA baseline system. Conversely, the study was also designed to provide the Shuttle EVA system designers an overview of specific payload task requirements. Designers of the EVA systems are not fully cognizant of experiment and payload requirements with potential extravehicular (EV) applications which may be economically advantageous in payload design and operation. Payload designers may not be aware of the availability of Orbiter subsystems and subsystem combinations that can be used to accomplish extravehicular tasks. This report is intended to promote the exchange of information between the payload experimenters and EVA system designers.

1.1 BACKGROUND

The economic constraints on manned space flight are more pronounced on the Space Shuttle Program than in previous U. S. space activities. Both the Space Shuttle launch system and the payloads are pursuing the most economical means of payload transportation and experiment development and operation as feasible without impacting experiment objectives or flight safety. Payload servicing and refurbishment studies have indicated that extravehicular on-orbit servicing is a prime candidate for economically satisfying payload operational requirements. Much of the EVA support equipment will be provided onboard the primary spacecraft, the Shuttle Orbiter, for safety and contingency situations. Eight Spacelab (Sortie) payloads and 6 Automated payloads are specifying planned EVA for on-orbit servicing in the early payload design phase. In addition, 97 Spacelab payloads of the 157 identified in the Marshall Space Flight Center Summarized NASA Payload Descriptions documents (Sortie Payloads--July 1975) specify EVA for contingency operations. The Automated payloads specify contingency EVA for 60 of the 84 payloads identified in August 1975.

The Shuttle EVA system is expected to play a major role in payload servicing and refurbishment on both currently defined and future payload missions. The EVA role is further enhanced since the Shuttle system will provide subsystems and equipment to perform three 2-man EVA operations of 6 hours duration on each 7-day Shuttle flight. One EVA capability, however, will always be reserved for contingency rescue operations. Orbiter-provided EV support equipment includes space suits, life support equipment, airlock, equipment servicing provisions, prebreathe subsystems, and all expendables and consumables at no cost to the payload. EVA capability in addition to the Orbiter provisions can be added as mission kits but chargeable to the payloads.

1.2 SCOPE AND APPROACH

The study effort comprised a combination of data identification, compilation, and analyses of EVA and payload systems followed by selection of potential EVA payload tasks, timeline and procedures development, conceptual designs, and presentation methodologies/formatting. The study consisted of five (5) major tasks and several related subtasks to reach the study milestones. The major tasks are listed below:

- Develop Shuttle EVA systems descriptions
- Identify and develop Shuttle EVA operational modes descriptions
- Identify and select representative EVA payload missions/tasks
- Develop payload EVA task completion plans
- Define payload EVA task support requirements and develop conceptual designs.

The overall study approach is illustrated in Figure 1.2-1. The study results presented in this volume of the final report include Tasks 1 and 2 of the overall study.

Task 1 provides a summary description of the Space Shuttle baseline EVA system(s) required to perform planned and candidate on-orbit payload

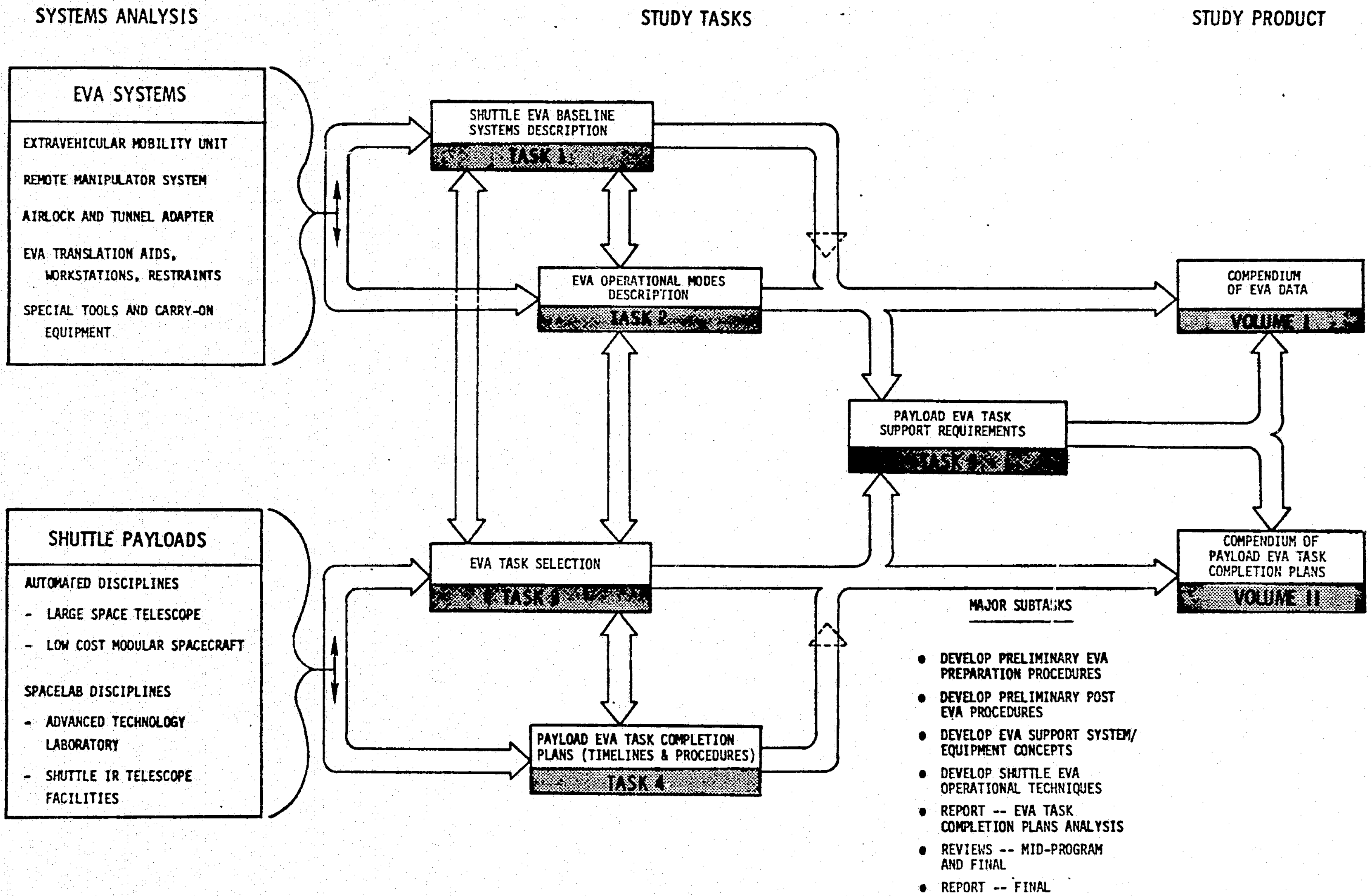


FIGURE 1.2-1: Study Approach and Task Interrelationship

servicing operations. The description provides the physical and operational characteristics of the baseline EVA system including illustrations and drawings. Task 2 identifies and provides a descriptive overview of the available EVA operational modes provided by the Shuttle Orbiter and available to support on-orbit payload servicing functions. The primary operational modes consist of: unaided EVA; EVA <u>with</u> the Remote Manipulator System (RMS); EVA <u>on</u> RMS; and EVA with a Manned Maneuvering Unit (MMU). The EVA operational modes description includes performance characteristics and limitations of each system.

Task 3 presents the results of specific payload analyses and selects potential EVA tasks to conduct typical EV missions. Payload analysis emphasis is placed on the payloads currently designing for planned EVA or studying concepts for EVA servicing, and payloads with potential cost savings through EVA utilization. Task 4 develops EVA procedures and timelines for conducting the typical EVA missions identified in Task 3. The EVA procedures will entail crewman operations from airlock egress through mission operations and terminate following airlock ingress. Task 4 identifies elements of the EVA mission including number of crewmen, translation aids and locations, workstation provisions, lighting, etc.

Task 5 identifies additional EVA support requirements (e.g., subsystems, tools, equipment) necessary to complete the representative payload EVA missions (EVA scenarios) developed as part of Tasks 3 and 4. The additional EVA support equipment requirements are not currently part of the Shuttle baseline EVA system (or payload systems) and are recommended primarily to enhance overall EVA operational capability. Payload task requirements that are beyond the capability of the baseline EVA system were also identified and support equipment defined to permit completion of specific EVA missions. The study results of Tasks 3 through 5 are presented in Volume II of this report.

SECTION 2.0 EVA SYSTEMS DESCRIPTION

2.1 INTRODUCTION

The Space Shuttle provides a full complement of EVA equipment on each flight to perform Orbiter, payload or rescue operations as required. Many experiment and payload organizations utilizing the Shuttle transportation system are not cognizant of the EVA provisions and the capability to accomplish a wide range of on-orbit functions outside the vehicle cabin. A summary description of the Shuttle baseline EVA system is provided as a familiarization aid to experiment and payload planners. The EVA systems description is designed to provide sufficient information for the payload planner to apply EVA to his experiment design as appropriate. The description is not intended to provide a critical detailed review of EVA system components or their complete functions within a subsystem. The EVA system physical and operational characteristics are emphasized, and the descriptions include supplementary information and limitations considered applicable to the payload community.

The Shuttle EVA system, for purposes of this study, includes all major subsystems of the currently identified baseline Orbiter EVA system. Additional EVA subsystems are included in the description as required to complete payload EV operations identified in Volume II, "Payload EVA Task Completion Plans", of this report. The additional EVA subsystems will include those in the following categories: (1) EVA subsystems not part of the current Shuttle baseline EVA system but previously developed and under study for Shuttle application, and (2) new EVA subsystem concepts as required to accomplish the payload EV operations addressed in Volume II of this report.

The Shuttle EVA subsystems described are categorized relative to the current Orbiter and payload requirements status. The subsystems described and the respective classifications are shown in the following table:

SPACE SHUTTLE EVA SUBSYSTEM	CLASSIFICATION		
	BASELINE EVA SYSTEM	UNDER STUDY FOR SHUTTLE APPLICATION	NEW SYSTEM TO ACCOMPLISH PAYLOAD TASKS
Extravehicular Mobility Unit	●		
Remote Manipulator System	●		
Airlock (Interior)	●		
Airlock (Exterior) and Adapter Tunnel	●		
EVA Translation Aids (Payload Bay)		●	
EVA Workstations and Restraints		●	●
Manned Maneuvering Unit	●		
EVA Mobility Aids (Payload Attached)		●	●
Special Tools/Equipment		●	
Portable EVA Lights			●

Several of the Shuttle EVA subsystems listed in the table possess a dual classification. These subsystems are currently under study by the NASA and/or payload organizations but not presently baselined as Shuttle flight hardware. The subsystems may also be a new system required to accomplish candidate payload EV functions. The Space Shuttle EVA systems descriptions are contained in the following subsections.

2.2 EXTRAVEHICULAR MOBILITY UNIT (EMU)

2.2.1 Introduction

Previous NASA manned space programs have required an Extravehicular Mobility Unit (EMU) for Extravehicular Activities (EVA) with the space suit separate from the life support system. This was required to permit the space suit to be used with the spacecraft environmental control system during launch, emergency return, and other non-EVA operations. The EMU design was often compromised as a result. Since the Space Shuttle EMU is designed for EVA only, previous constraints which dictated separable suit and life support subsystems, soft suits for couch interface and vented comfort are eliminated. This has allowed an opportunity for functionally innovative designs to be tailored to the specific needs of Space Shuttle EVA.

The Space Shuttle EMU design concept is consistent with the overall philosophy of the Space Shuttle Program which dictates that manned space flight must progress from the relatively high cost, specialized venture of previous programs into a low cost, high yield, routine operation. The NASA design concept as shown in Figure 2.2-1 requires the operation of only four major components by the crewman in donning and doffing. This concept has been conceived in an effort to: (1) minimize both ground and in-flight operations, (2) increase crew safety by minimizing hoses, eliminating straps, and minimizing pressure bladder penetrations; and (3) providing readily accessible controls and displays. With the program philosophy of high launch frequency at minimum cost, NASA is developing highly reliable systems requiring minimum maintenance and operations. The operational aspects of the Space Shuttle Program dictate that costly, time consuming operations, such as prelaunch checkout and in-flight operations, must be reduced to the minimum. Integration of the NASA design concept is aimed toward this end.

The NASA Shuttle EMU design was conceived to provide suit features on a non-customized basis to eliminate costly customizing, crew scheduling for fit checks, and rework. Standard sizing also provides flexibility in crew

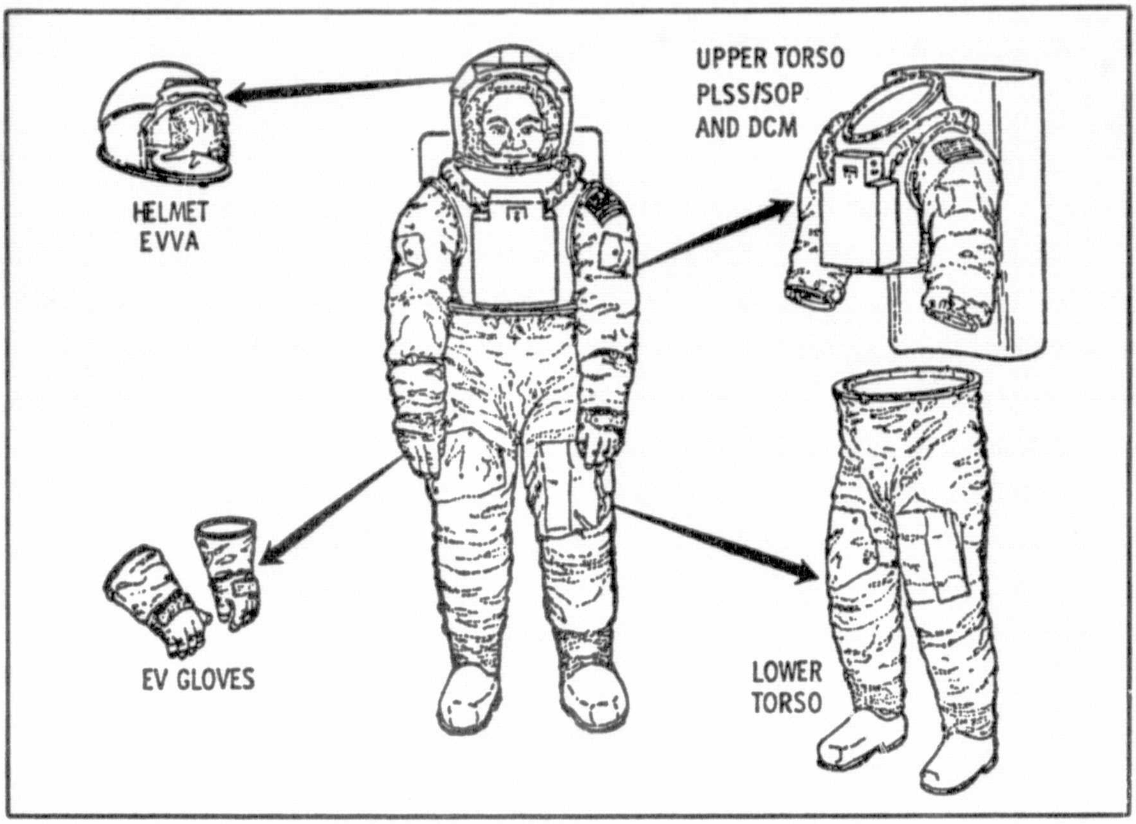


FIGURE 2.2-1: Space Shuttle EMU

selection by providing an inventory of standard subsystems for assembly of a "sized" EMU. The hard upper torso minimizes shelf life and maintenance problems, while increasing safety with its inherent structural features. The upper torso provides structural mounting for the life support subsystems.

The EMU will accommodate crew energy rates which do not exceed an average metabolic expenditure of 70 gm-cal/sec (1000 BTU/hr) with a 112 gm-cal/sec (1600 BTU/hr) expenditure for any one hour of the EVA. Peak activity levels of up to 140 gm-cal/sec (2000 BTU/hr) for periods not exceeding 15 minutes can be accommodated. The EMU consumables (i.e., breathing oxygen, cooling water, and electrical power) are sized for 490 gm-cal (7000 BTU) total EVA metabolic expenditure which will support a 6-hour EVA with an additional 30 minutes for egress/ingress activities and a 30-minute contingency

reserve. Although the EMU is designed to support two planned and one contingency EVA's per mission (with recharge of consumables between each EVA), it can be recharged in flight as often as required for additional EVA's when consumables are available.

Subsequent information contained in this section reflects the current baseline for EVA equipment. However, much of the equipment is in the early design stage and capabilities/operation will change as the program matures.

2.2.2 EMU Systems Description

The Space Shuttle EMU is a complete anthropomorphic system which provides pressure, ventilation, humidity and thermal control, and communications for the crewman during EVA. The EMU will allow the extravehicular (EV) crewman to operate in the earth orbital space environment while in the open payload bay or remote from the Orbiter external surface. The EMU design provides for an unassisted one-man EVA without compromising the normal two-man EVA operational mode.

The EMU design concept consists of the subsystems listed in Figure 2.2-2. However, it is more convenient to group the subsystems into three areas for ease of EMU description: (1) the space suit assembly (SSA); (2) life support subsystems (LSS); and (3) service and cooling umbilical (SCU). The subsystem groupings comprising these areas are presented in the following subsections.

2.2.2.1 Space Suit Assembly (SSA)

The SSA is the EMU assembly which encloses the crewman's body, limbs, and head in an anthropomorphic pressure vessel. The EMU subsystems included in this assembly are the following:

- Hard Upper Torso
- Arms (Left and Right)
- Lower Torso
- Liquid Cooling Garment (LCG)
- Urine Collection Device (UCD)
- Insuit Drink Bag (IDB)

• Primary Life Support Subsystem (PLSS)	• Helmet
• Battery	• Gloves (Left and Right)
• Displays & Controls Module (DCM)	• Liquid Cooling Garment (LCG)
• Contaminant Control Cartridge (CCC)	• Extravehicular Visor Assembly (EVVA)
• EMU Electrical Harness (EEH)	• Urine Collection Device (UCD)
• Secondary Oxygen Pack (SOP)	• Insuit Drink Bag (IDB)
• Service and Cooling Umbilical (SCU)	• Communications Carrier Assembly (CCA)
• Hard Upper Torso (HUT)	• Biomedical Instrumentation System
• Arms (Left and Right)	• Extravehicular Communications System (EVCS)
• Lower Torso	• EMU Antenna

FIGURE 2.2-2; Space Shuttle EMU Subsystems

- Helmet
- Gloves (Left and Right)
- Extravehicular Visor Assembly (EVVA)
- Communications Carrier Assembly (CCA)
- Biomedical Instrumentation System

The SSA subsystems are depicted in Figure 2.2-3.

The SSA pressure vessel design includes the features as shown in Figure 2.2-4. The upper torso, exclusive of the arms, is a rigid structure with provisions for structural mounting and connecting the life support subsystems modules (i.e., DCM and PLSS/SOP). The hard upper torso also provides for attachment of the helmet, arms, and lower torso and incorporates part of the ventilation distribution system. The arms and lower torso are constructed of soft fabric. Both the arms and legs/boots are interchangeable with the various sizes of torso elements which allows assembly of a properly fitting garment for different size crewmen. The upper and lower torso elements are connected at the waist by a pressure sealing rotary bearing closure which

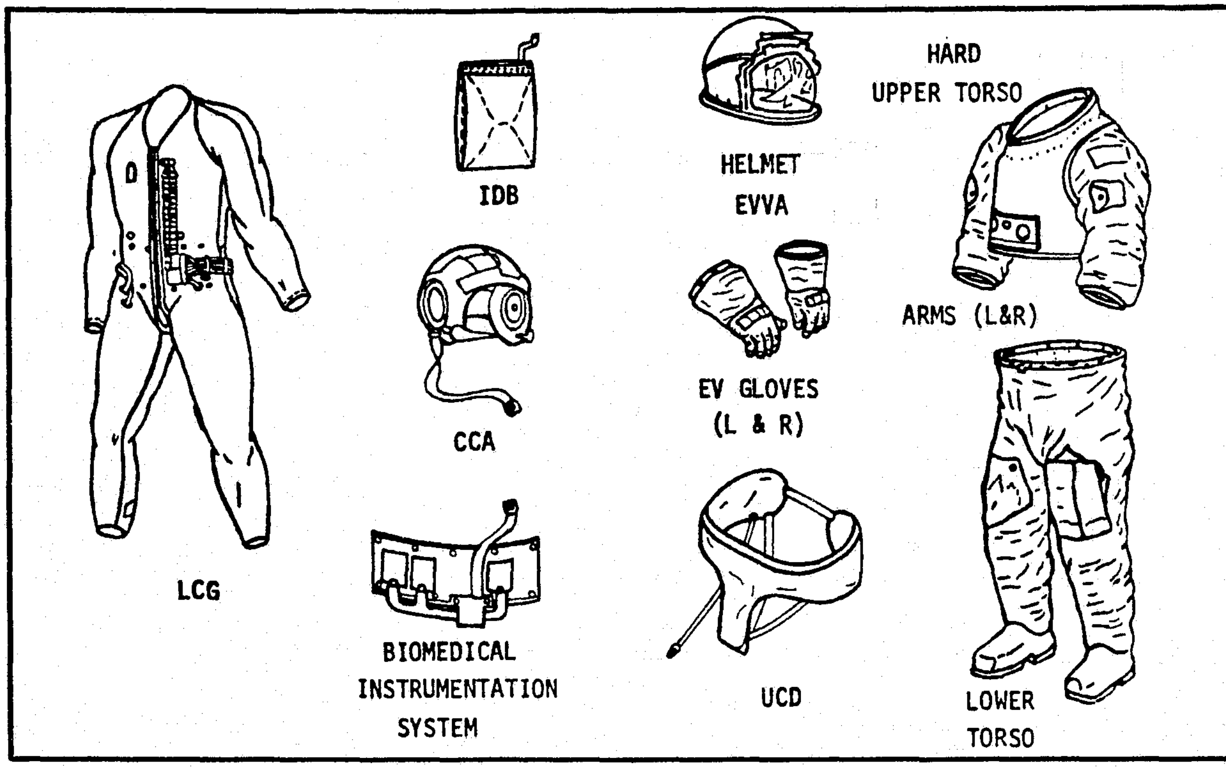


FIGURE 2.2-3: Space Suit Assembly Subsystems

allows rotation of the upper torso and accommodates easier donning and doffing. The helmet is a detachable, rigid, one-piece hemisphere fabricated of ultraviolet (UV) stabilized polycarbonate. Donning of the helmet automatically aligns and interconnects the upper torso and helmet portions of the ventilation system. The extravehicular visor assembly (EVVA) is a system of visors, pivot and latch mechanisms, center and side shades, and support devices which cover the helmet to provide impact, thermal and solar radiation protection for the crewman. The EVVA visors are fabricated of UV stabilized polycarbonate with thermal/optical coatings applied on the inner surfaces.

The EV gloves are non-custom, standard sizes for interchangeability to fit different size crewmen. The gloves provide ventilation to the finger and palm areas and have an outer abrasion resistant covering. The gloves are capable of withstanding contact temperatures of -117.8°C to +93.3°C

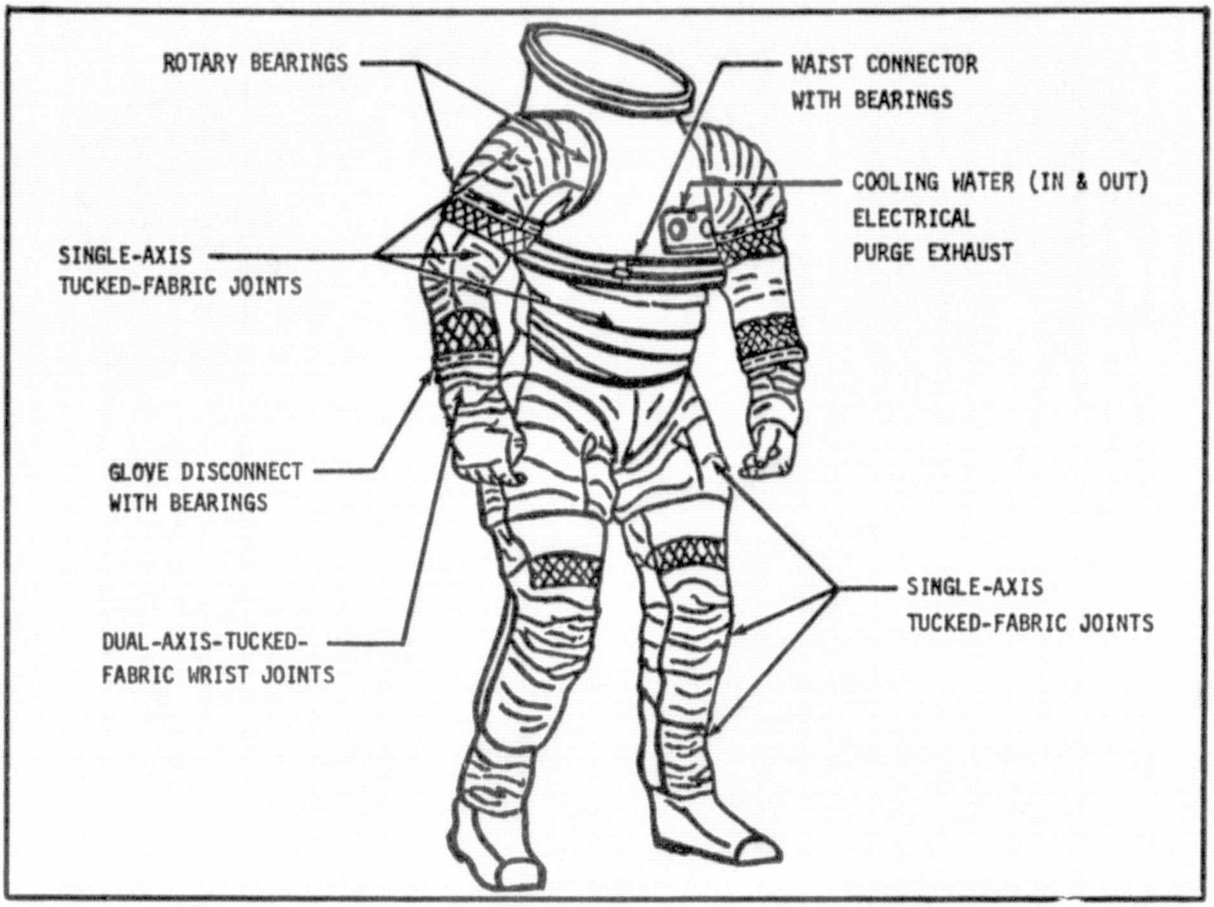


FIGURE 2.2-4: SSA Pressure Vessel Design Features

(-180°F to +200°F) at a contact pressure of 0.14 kg/cm^2 (2 psi) minimum without causing undue discomfort to the crewman's hand. They are molded to provide minimum restriction to mobility and maximum finger dexterity/ tactility practical to allow grasp retention for extended periods (5 minutes) without hand fatigue.

The exterior of the SSA is protected from thermal environment extremes and micrometeoroid penetration by an integrated covering. The protective covering consists of three functional layers: the outer layer provides abrasion and snag protection; the center layer provides thermal protection (radiation shields and insulation spacers); and the inner layer functions as an abrasion liner, a stress-relief layer, and the final penetration-

resistant layer for micrometeoroids. The thermal insulation is sufficient to maintain a uniform temperature on any interior surface between + 10°C and +43.3°C (+50°F and +110°F) during all phases of the mission.

Five subsystems of the SSA are worn by the crewman inside the pressure vessel. They are the liquid cooling garment (LCG), urine collection device (UCD), insuit drink bag (IDB), communications carrier assembly (CCA) and biomedical instrumentation system.

The LCG is a moderately form-fitting, flexible garment (similar to full length underwear) that is worn next to the crewman's skin. It provides general comfort, perspiration absorption (for thermal transfer to the ventilation system), and body cooling. Flexible tubing woven into the garment provides for thermal transfer of crewman metabolic heat to the recirculating liquid cooling system. The LCG liquid cooling connector interfaces with the DCM at the front of the hard upper torso and is provided with a positive locking feature.

A 950-ml. (32 oz. U.S. liquid) flexible container, the UCD, is worn by the crewman to collect and retain urine voided by the crewman during EVA. It is held in place with an adjustable harness and employs a replaceable roll-on-cuff as the crewman interface. Incorporated into the UCD is a positive shutoff drain valve which interfaces with the Shuttle Orbiter waste management system for draining of collected urine from the UCD after doffing the suit.

The insuit drink bag (IDB) is a flexible pouch worn inside the upper torso at the neck ring. The bag holds up to 950 ml. (32. oz.) of potable water for drinking during suited operations. A drink tube/valved mouthpiece, actuated by the crewman using head motions, will allow the crewman to drink by means of a sucking action. The unit can be filled prior to, or after, installation into the upper torso (before donning torso) by way of a fill valve that interfaces with the Orbiter potable water dispenser.

The CCA is a head-fitted, soft goods assembly containing encapsulated microphone and earphone electronic modules mounted in a "Snoopy-type" skull cap. Stabilized positioning of the microphones with respect to the mouth is provided. The CCA, as part of the overall communications system, provides the crewman with RF voice transmission and reception and audible commands from the caution and warning portion of the life support subsystems.

The bioinstrumentation system provides a means to gather physiological parameters considered necessary for determining the well-being of the crewman and insure his safety from a ground-based medical viewpoint. The parameters identified to date for medical monitoring during Space Shuttle EVA's are electrocardio-activity and subject identification. The conditioned biomedical signals are provided to the extravehicular communications system (EVCS) by the EMU electrical harness (EEH) for telemetry transmission to the Space Shuttle Orbiter.

2.2.2.2 Life Support Subsystems

The life support subsystems include all the life support conditioning and control components, consumables (oxygen, cooling water, electrical power), and voice and telemetry communications for EV operations. The subsystems are packaged in two modules: one mounted on the front, the other integrated into the back of the hard upper torso. The front-mounted unit is the displays and control module (DCM); the back-mounted module contains the primary life support subsystem and secondary oxygen pack (PLSS/SOP). All interfaces with the hard upper torso are through panels located behind the modules, minimizing the use of umbilicals, hoses, etc. The structural mounting interfaces between the life support modules and the upper torso are depicted in Figure 2.2-5. The EMU is considered a single unit throughout the mission; however, in a contingency situation the PLSS and SOP can be separated and removed from the upper torso by the crewman using standard tools.

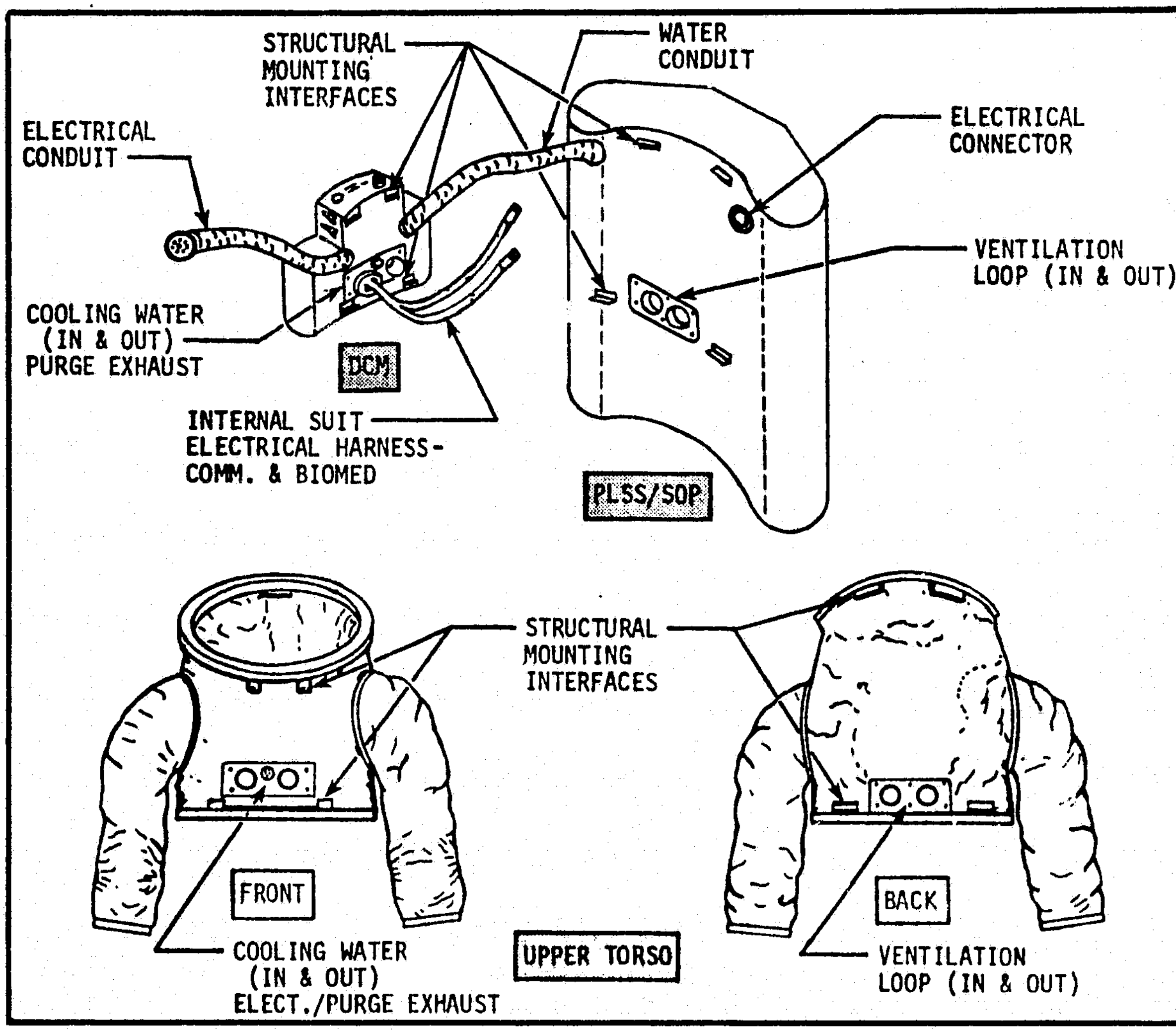


FIGURE 2.2-5: EMU Internal Interfaces

The PLSS is a rechargeable, self-contained module that provides the expendables and hardware to perform the following EMU control functions: (1) pressure, (2) ventilation, (3) thermal, (4) humidity, and (5) contamination control. The subsystem also provides voice and telemetry communications and caution and warning.

For descriptive purposes the PLSS is subdivided into five subsystems: (1) primary oxygen, (2) gas ventilation circuit, (3) water transport loop, (4) feedwater loop, and (5) electrical systems.

The primary oxygen system stores and supplies expendable oxygen on a demand basis for crewman breathing and suit purge and pressurization.

The gas ventilation circuit uses a fan to provide recirculating oxygen flow over the crewman's oral-nasal area and body extremities for respiratory requirements, temperature control (to supplement the LCG), transport of biologically produced gases, toxicants and perspiration. An in-flight replaceable contaminant control cartridge (CCC) in the ventilation circuit removes particulate matter, trace gas contaminants and carbon dioxide using a filter, activated charcoal and anhydrous lithium hydroxide, respectively. Humidity control is maintained by condensing and storing excess water (from crewman respiration and perspiration) which is removed by a water separator and pumped into a feedwater loop.

The water transport loop circulates thermally conditioned water through the PLSS and LCG to remove crewman metabolic heat, external environmental heat leak (inward), and EMU systems generated heat. A constant impedance type control valve, located on the DCM, allows the crewman to select the liquid cooling rate through the LCG while by-passing the remaining water.

The feedwater loop stores and supplies expendable water on demand to a porous plate sublimator--the primary PLSS heat-rejection system. The electrical systems provide power, processing and distribution functions to perform status monitoring, caution and warning and communications. The extravehicular communications system (EVCS) provides the following basic capabilities:

- Primary and backup duplex voice communications between Orbiter/ground and one or both of the EV crewmen
- Uninterruptable voice communications between the EV crewmen
- Simultaneous and continuous telemetry from the EV crewmen to the Orbiter
- Thirty telemetry channels, 30 by 1-1/2 pulse amplitude modulation (PAM), per each extravehicular communicator (EVC) with 26 channels available for performance and status information

- Separate subcarrier frequencies for continuously monitoring of each crewman's ECG during EVA
- An audible alarm for 10 ± 2 seconds in the event of an unsafe condition.

Instrumentation includes both analog and alarm signal sensors. The caution and warning/monitoring system includes PLSS expendables and system performance parameters with both visual display and tone annunciation. The C&W system has corrective action displays and maintains crew safety status indication without requiring Orbiter or ground inputs. The EMU electrical harness (EEH) contains the necessary wiring, including redundant critical circuits, to provide the distribution functions (input/output) between the PLSS/SOP, DCM, CCA and bioinstrumentation system.

The secondary oxygen pack (SOP), a non-inflight rechargeable unit mounted on the bottom of the PLSS, is a functionally independent, automatically activated backup life support system for the EMU. The SOP supplies a 30-minute minimum emergency oxygen supply sized to support a 70 gm-cal/sec (1000 BTU/hr) metabolic load in the event of a PLSS malfunction or failure.

The display and control module (DCM) contains all displays and controls required for one-man operation of the EMU. The controls and displays include: fan switch, water pump switch, communications mode selector switch and volume control, PLSS oxygen quantity indicator, suit pressure gage, cooling control valve, purge valve and status indicators. The purge valve accommodates the emergency purge and oxygen purge at donning to flush nitrogen out of the EMU. The status indicators incorporate emergency corrective action display. The location and size of the DCM is such that the crewman can see his feet without difficulty, and all controls are visible and easy to reach. The controls are protected to prevent inadvertent actuation by the crewman or equipment interfaces. The DCM also contains the EMU battery and includes the suit electrical harness up to the CCA (reference Figure 2.2-5).

The power supply for the EMU is an eleven-cell, silver-zinc battery weighing 4.4 kg. (9.8 lbs.), which supplies 16.8 volts DC nominal for up to seven hours after eleven complete discharge and recharge cycles. The battery is replaceable inflight without the use of special tools and can be recharged either installed or removed from the DCM using a battery charger provided in the Orbiter airlock. A completely discharged battery can be recharged requiring a maximum of 16 hours.

The contaminant control cartridge (CCC) is an inflight-replaceable unit weighing 2.5 kg. (5.5 lbs.). Each cartridge supports a seven-hour EVA.

2.2.2.3 Service and Cooling Umbilical (SCU)

The SCU is an umbilical approximately 2.1 meters (7 ft.) in length which provides the interface between the EMU and Orbiter airlock support subsystem (see Section 2.4, this report) during pre-EVA preparation and post-EVA activities, including PLSS recharge and EMU drying. The SCU is shown schematically in Figure 2.2-6. The umbilical allows the Orbiter systems

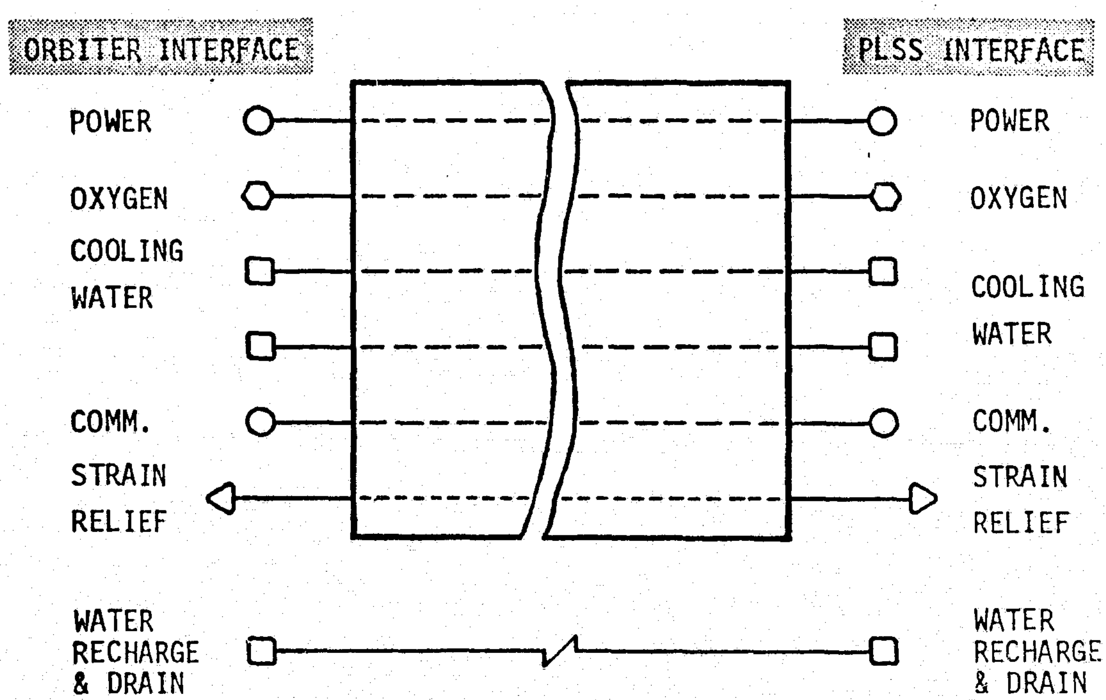


FIGURE 2.2-6: EMU Service and Cooling Umbilical Schematic

to provide the EMU with electrical power, makeup oxygen, heat-rejection and hardline voice communications capabilities for the suited crewman until the PLSS systems are fully operational. The Orbiter heat-rejection system is utilized until the PLSS subsystem becomes effective after airlock depressurization. By utilizing the Orbiter supplies, the PLSS consumables are reserved for EVA activities. The SCU is designed to allow safe, unassisted (one-man), vacuum connection so that life support can be provided upon return to the airlock and during repressurization. The umbilical is also used to drain condensate water, to resupply the PLSS feedwater and oxygen, and to recharge the battery from the Orbiter systems.

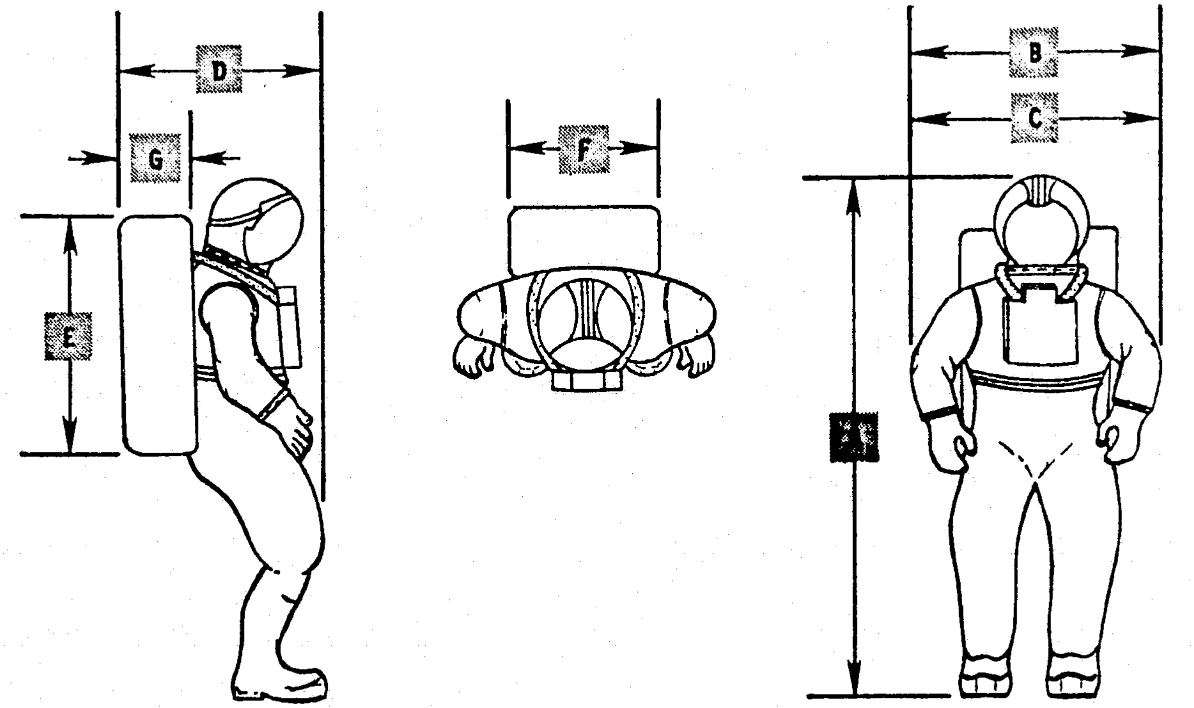
2.2.2.4 Weight and Envelope

The pressurized EMU overall physical dimensions are shown in Figure 2.2.-7. For unencumbered translation, these dimensions dictate a minimum unobstructed one meter (40 in.) diameter translation corridor. The total weight of the unit, excluding 5.3 kg. (12 lbs.) of cooling water is approximately 91.4 kg. (203 lbs.). This weight includes 2.5 kg. (5.6 lbs.) of oxygen and a 4.4 kg. (9.8 lbs.) battery. The EMU is designed so that the center-of-gravity of a suited crewman is within 10.1 cm. (4 in.) vertically and 7.6 cm. (3 in.) horizontally of the center-of-gravity of a nude, standing crewman. The "at-rest position" of the EMU and the variance in the center-of-gravity generally result in a crewman's resting (or most comfortable) position being slightly hunched and somewhat shorter than the preceding dimensions would indicate.

2.2.3 EMU Performance Characteristics

The EMU provides the EV crewman with the capability to perform EVA while in earth orbit to support Space Shuttle functions. The EMU performance is based on the EV requirements of the Shuttle missions and will permit the crewman to perform the following typical tasks:

- Inspection, photography, and possible manual override of vehicle and payload systems, mechanisms, and components



DIMENSION	PERCENTILE MAN 5%		95%	
	Cm.	In.	Cm.	In.
A - Height	171.5	67.5	192.8	75.5
B - Maximum Breadth at Elbows (Arms Relaxed)	-	-	74.7	29.4
C - Maximum Breadth at Elbows (Arms at Side)	-	-	67.1	26.4
D - Maximum Depth with Primary Life Support System (PLSS) and Secondary Oxygen Pack (SOP)	66.0	26.0	72.1	28.4

	Cm. (Max.)	In. (Max.)
E - PLSS/SOP Height	78.7	31
F - PLSS and SOP Breadth	53.3	21
G - PLSS and SOP Depth	17.8	7

FIGURE 2.2-7: Space Shuttle EMU Dimensions (Preliminary)

- Installation, removal, and transfer of film cassettes, material samples, protective covers, and instrumentation
- Operation of equipment including assembly tools, cameras, and cleaning devices
- Cleaning of optical surfaces
- Connection, disconnection, and stowage of fluid and electrical umbilicals
- Repair, replacement, calibration and inspection of modular equipment and instrumentation on the spacecraft or payload
- Replacement and repositioning of antennae
- Conduct extravehicular experiments
- Operation and servicing of free flying maneuvering units
- Translation to and from work sites, attachment and release of crewman restraints, equipment restraints, and attachment of tethers to crewman and spacecraft
- Activation and handling of Shuttle passenger Personnel Rescue Systems to effect free-space transfer from a disabled Orbiter to a rescue spacecraft.

2.2.3.1 Duration/Operation

The EMU is designed to support a seven-hour EVA; however, 30 minutes of the seven hours are dedicated to egress/ingress activities and another 30 minutes for contingency reserve resulting in a six-hour period for actual payload support activities. This nominal six-hour period is based on an average crewman metabolic rate of 70 gm-cal/sec (1000 BTU/hr) with a 112 gm-cal/sec (1600 BTU/hr) maximum rate for any one hour of the EVA. A typical metabolic rate profile for a six-hour nominal EVA is shown in Figure 2.2-8.

The EMU is operable in any ambient environment between 0 and 760 mmHg (14.7 psia) pressure. When operating at 0 mmHg, the internal suit pressure is maintained at a nominal 206.8 mmHg (4.0 psia) except for contingency situations when the SOP is used. In the contingency situation, the SOP

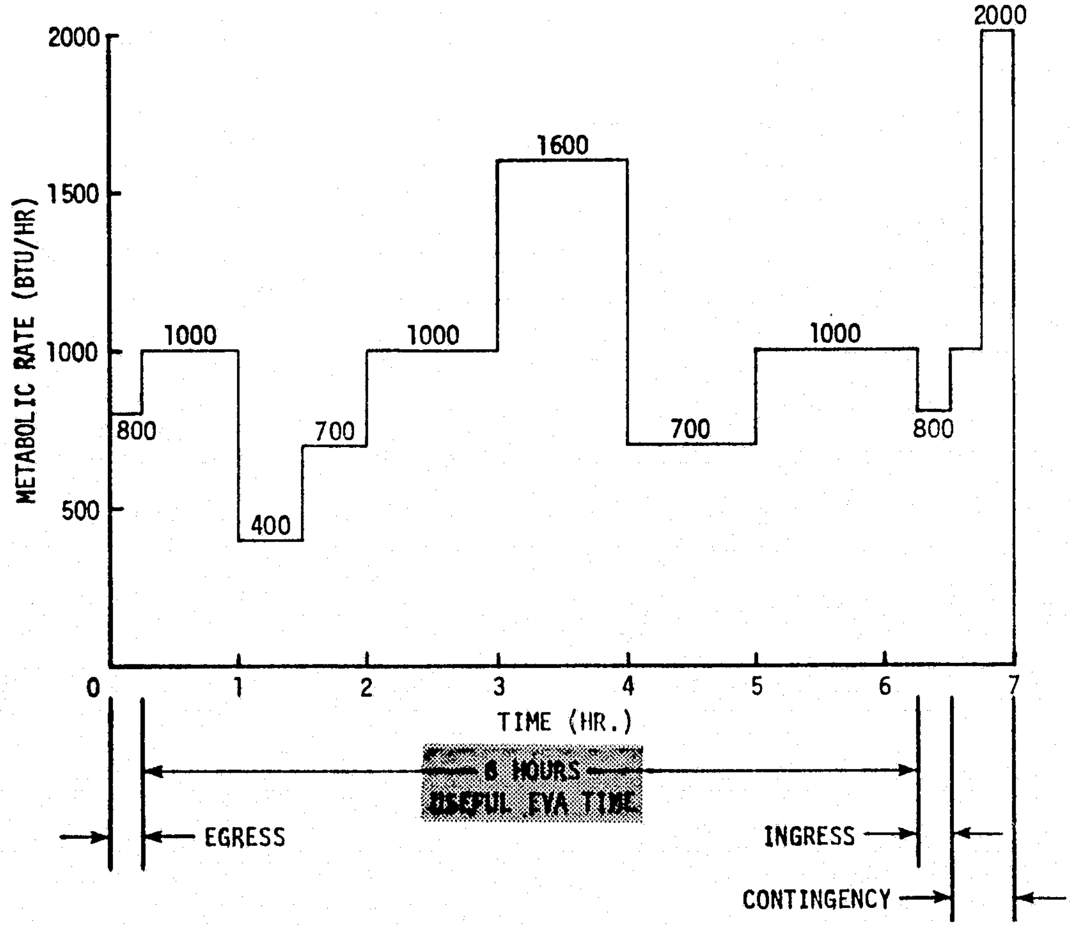


FIGURE 2.2-8: Metabolic Rate Profile for a Nominal EVA

maintains the pressure at a minimum of 173.2 mmHg (3.35 psia). It should be noted that although the EMU is operable between 0 and 760 mmHg, the PLSS heat-rejection system is only operable at or near vacuum conditions. Closed loop water cooling is supplied to the EMU through the SCU by the Orbiter environmental control and life support system (ECLSS) prior to vacuum operation.

2.2.3.2 Contamination

The baseline EMU (i.e., an EMU operating without an umbilical) is the source of three contaminants: water vapor from the PLSS heat-rejection system sublimator, gases and trace organics from EMU leakage, and particulate matter from equipment and suit surfaces. When compared to Orbiter

cabin leakage and its systems contaminants, the EMU contaminants appear to be insignificant; however, the water vapor ejected from the PLSS sublimator may be of significance to payloads. Table 2.2.1 summarizes the EMU contaminants.

TABLE 2.2.1: EMU Contaminants Summary

CONTAMINANT	SIZE	QUANTITY		SOURCE
	microns	kg./hr.	lb./hr.	
Particles	0.5-500			Dust, lint, metal
Water Vapor		2.4×10^{-4}	5.4×10^{-4}	Suit leakage
Gases		7×10^{-3}	15.8×10^{-3}	Suit leakage
Organics		4.3×10^{-6}	9.5×10^{-6}	Trace offgassing
Water Vapor		77×10^{-2}	107×10^{-2}	Sublimator evaporant

Although the capability exists to interface the PLSS to an umbilical to obtain heat-rejection from the Orbiter rather than from the PLSS sublimator, an umbilical of sufficient length to operate in the payload bay is not currently baselined.

2.2.3.3 PLSS Recharge

The EMU can be launched fully charged and ready for use. If, however, more than one EVA is performed during a mission, the PLSS must be drained of condensate water, recharged with feedwater and oxygen, and the battery either recharged or replaced. Oxygen, potable water, and power are supplied from the Orbiter ECLSS and avionics systems through the airlock support subsystem, thereby allowing the crewman to recharge the PLSS using the SCU. The quantity of oxygen and water required to recharge the EMU varies according to the length of the previous EVA, but the maximum quantities per EMU are 5.4 kg. (12 lbs.) of water and 0.72 kg. (1.6 lbs.) of oxygen. The maximum battery charging requirement is 30 amp-hours within

16 hours. In addition, the contaminant control cartridge must be replaced in the PLSS.

The PLSS is capable of being recharged by one man within one hour if a replacement battery is used (i.e., no battery recharge).

2.2.3.4 EMU Drying

Microbial control is a requirement for the Shuttle EMU. Fungi will grow at 21.1°C (70°F) and 65 percent relative humidity. Visible growth is time dependent, but detrimental effects to the hardware, particularly the suit, will occur before fungal growth is apparent. On a seven-day mission, if the EMU is not dried after use, fungal growth will occur and over a period of similar use degrade the material and shorten the life of the EMU.

The following criteria have been established to prevent microbial growth in the EMU. The EMU will be dried after each use; the maximum amount of water permitted to remain in the suit after drying is 50 grams (0.11 lb.). The acceptable relative humidity in the EMU while in storage is 55% maximum. Drying is to be initiated as soon as possible after doffing but not later than 12 hours. There may be additional usages within the 12-hour period, provided that suit drying can be initiated within the 12-hour period from first usage doffing. The maximum elevated temperature permitted during suit drying is 48.9°C (120°F). The EMU drying times are 48 hours nominal and 60 hours maximum.

If the EMU equipment becomes visibly contaminated and reuse is required, a thorough cleaning of the contaminated areas with a disinfectant (Betadine) is recommended. The present baseline concept to accomplish EMU drying is to use desiccant cartridge(s) located in the ventilation circuit with gas circulated through the closed loop.

2.2.3.5 Mobility

The effectiveness of a crewman performing EVA tasks is dependent on numerous factors; two of the most crucial are the design mobility of the EMU and the availability of proper restraints and translation aids. Figure 2.2-9 shows the minimum EMU joint mobility ranges and the associated internal suit torques. The torques are sufficiently low to allow maximum mobility without causing excessive fatigue to the crewman.

2.2.3.6 Reach

A crewman's reach is a function of his size, the crewman restraint system, and the suit mobility. In general, a crewman's reach, when he stands erect, varies from approximately 0.53 to 0.64 m. (21-25 in.) depending on stature. The reach envelope is expanded considerably, however, when the crewman is properly restrained in foot restraints or provided with hand holds. Figures 2.2-10 and 2.2-11 demonstrate reach capability variations depending on the mode of restraint. A crewman in foot restraints, for example, can pivot about the ankles, and his reach in the immediate area is limited only by his agility.

2.2.3.7 Dexterity

While a suited crewman can readily perform fine manipulations, tactility is diminished by the gloves. In general, visual feedback or the use of alignment guides, detents, and similar aids provide assistance to tactile feedback in performing critical manipulations.

2.2.3.8 Visibility

With head movements, the EMU provides an unrestricted field-of-view of 120 degrees to the left and 120 degrees to the right in a horizontal plane and 105 degrees down and 90 degrees up in the vertical plane. The minimum critical field-of-view, with the head and eyes fixed in a normal position, is shown in Figure 2.2-12.

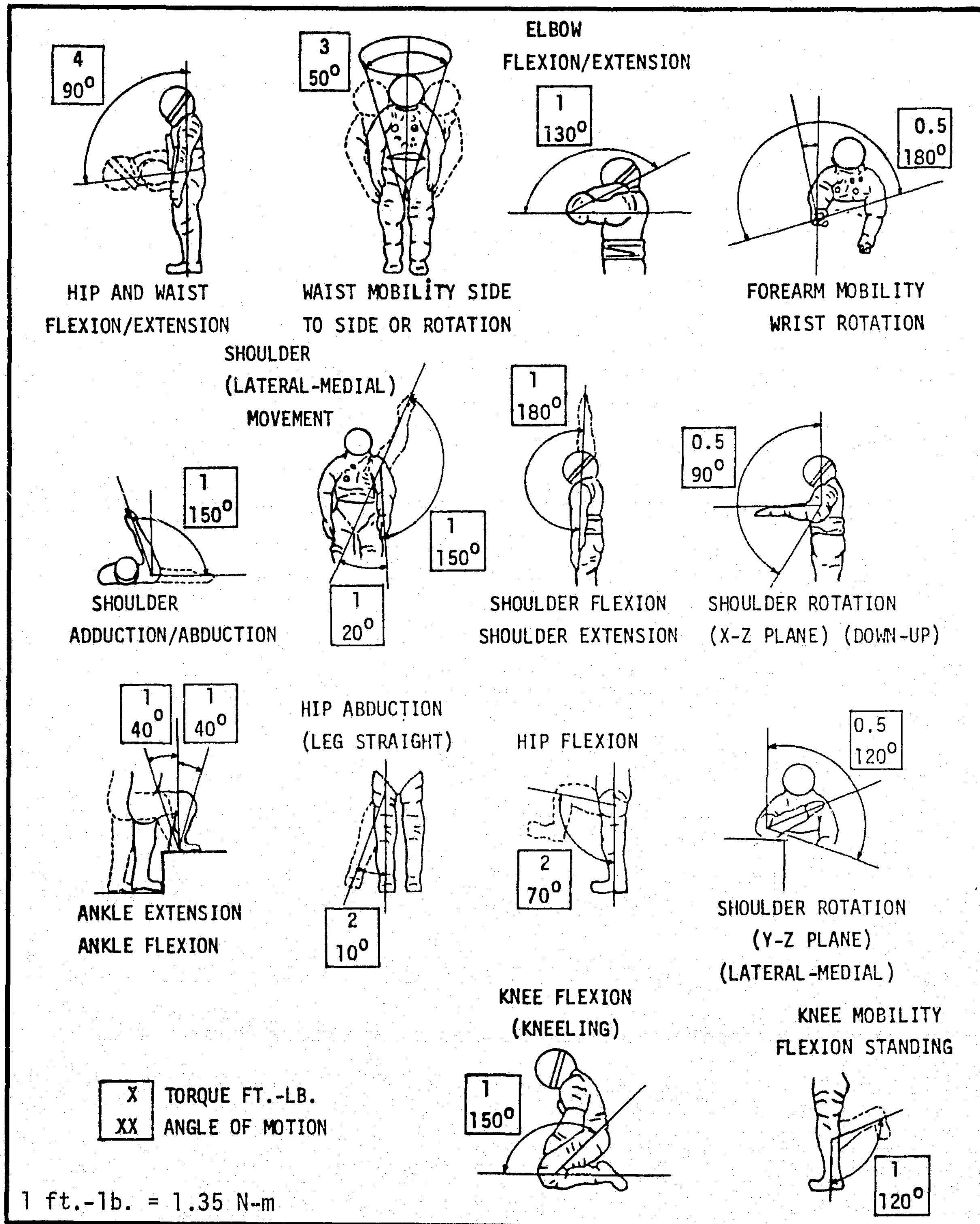


FIGURE 2.2-9: EMU Joint Mobility Characteristics

SPACE SHUTTLE EVA

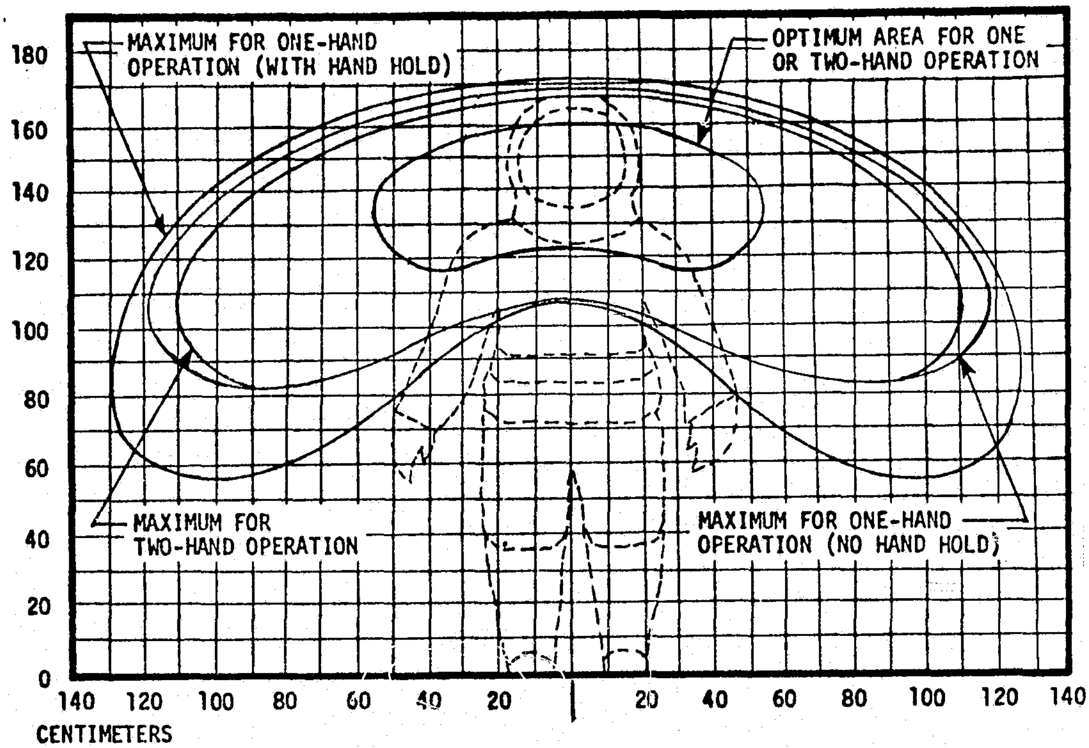


FIGURE 2.2-10: EVA Crewman Side Rea… Envelope

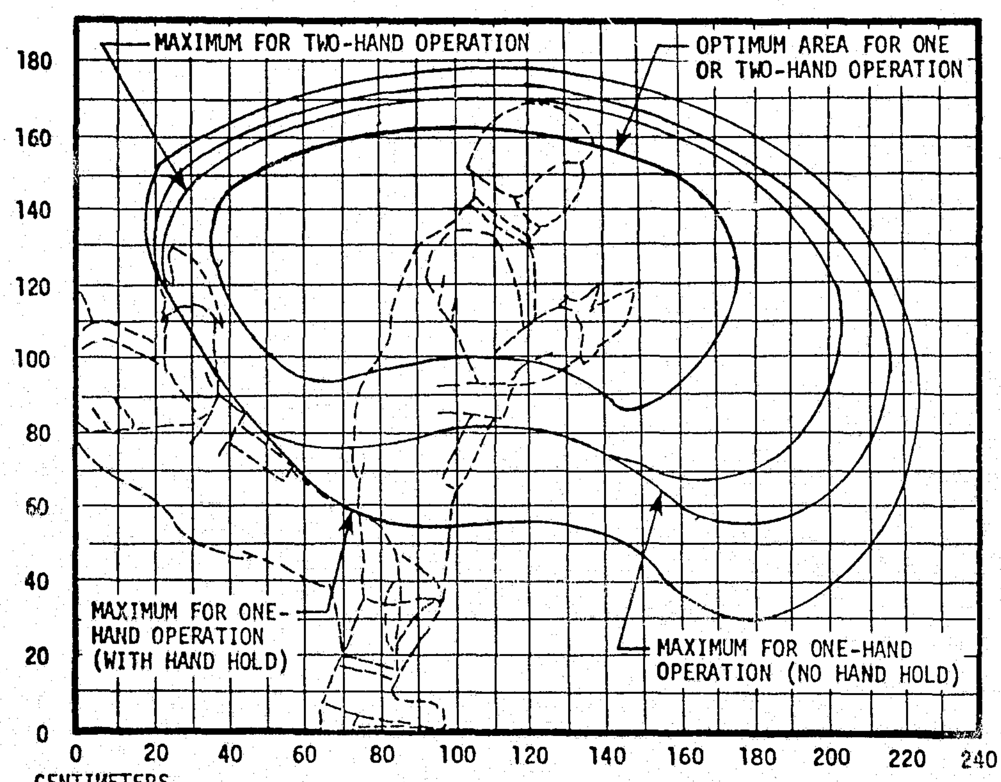


FIGURE 2.2-11: EVA Crewman Fore-Aft Reach Envelope

Temporal	90^{o}
Superior-temporal	62^{o}
Superior	85^{o}
Inferior-temporal	85^{o}
Inferior	70^{o}

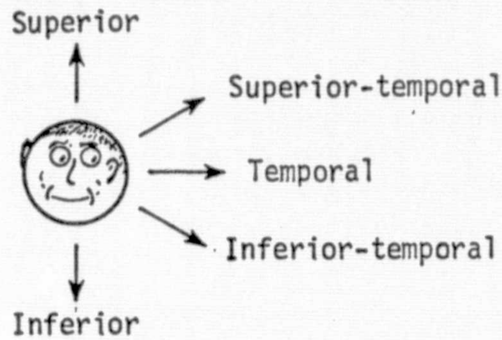


FIGURE 2.2-12: EV Crewman Minimum Critical Field of Vision
(Head and Eyes Fixed in Normal Primary Position)

2.2.4 EVA Operational Phase

The term EVA refers to any condition in which the EMU external ambient pressure is below 206.8 mmHg (4.0 psia). An EVA operation progresses through three phases. The first is pre-EVA activities, the second is the actual EVA and the third phase is post-EVA.

2.2.4.1 Pre-EVA Phase

Pre-EVA activities encompass all EV crewman tasks in preparation for an EVA until the airlock pressure drops below 206.8 mmHg (4.0 psia). EVA activities begin with the initiation of EV crewman prebreathing (denitrogenization) using a portable oxygen system (POS). The POS is a multiple use item of rebreather type design which, in addition to the EVA prebreathe application, can provide life support and eye protection from a contaminated cabin atmosphere. The POS is the primary life support during EVA rescue operations using the Personnel Rescue System (PRS). Oxygen is supplied to the POS from the Orbiter 56.3 kg/cm^2 (900 psi) system at stations located on the flight deck, mid-deck and in the airlock. A rechargeable storage bottle, integral to the POS, contains 0.45 kg. (1.0 lb.) oxygen and provides "walk around" capability inside the vehicle and is the mode to be used in the event of EVA rescue via PRS.

The EVA crewman begins EVA preparation by configuring the mid-deck and airlock for EMU donning. EVA prep includes retrieving and positioning EVA equipment and donning aids. Special equipment, including cameras, tools, etc. are prepared and checked for the EVA operations. Ancillary suit equipment, such as waste management, bioinstrumentation harness, and LCG are donned immediately prior to EMU donning. The IDB is serviced with potable water and installed in the suit upper torso. The EMU, less helmet and gloves, is donned. The crewmen then doffs the POS, dons the helmet and gloves, initiates the EMU oxygen purge, and continues the prebreathe cycle. Functional checks of the life support equipment and Orbiter communications systems, including backup modes, are completed and airlock depress initiated. Prior to airlock depress completion, the crewmen perform a pressure integrity check of the EMU and activate the PLSS heat-rejection feedwater system.

2.2.4.2 EVA Phase

The EVA phase activities begin during the airlock depressurization. The crewmen disconnect and stow the SCU's after depress. The outer airlock hatch is opened, and the crewmen rest until sufficient cooling is provided by the PLSS. The crewmen then egress the airlock to perform the required EVA tasks. Following task completion, the crewmen ingress the airlock, close the outer hatch and initiate repressurization.

2.2.4.3 Post-EVA Phase

The post-EVA phase begins when the airlock pressure increases above 206.8 mmHg (4 psia) and proceeds through the activities required to return the crewmen to the Orbiter shirtsleeve environment. The crewmen then perform a recharge of the PLSS (see Section 2.2.3.3 of this Volume) and prepare the equipment for the next EVA. EMU drying (see Section 2.2.3.4 of this Volume) completes the post-EVA activities, except for stowage of loose equipment and donning aids.

2.2.5 Operational Interfaces

Although designed specifically for zero-gravity operations with little or no compromise with other considerations, the EMU obviously has inherent limitations. To make the EVA performance as efficient as possible, payload designers must be aware of EMU limitations and factor them into payload designs to achieve the most practical man-machine interface possible. References 2.2.2 through 2.2.5 contain a compilation of applicable criteria which address human factors, crew station design and operations specifications.

2.2.5.1 Restraints and Translation Aids

The capability of a suited crewman is enhanced dramatically when proper restraints are available during translation and at the worksite. Restraints and translation aids are discussed in Sections 2.6 and 2.7 of this report.

2.2.5.2 Cargo Handling

Many variables influence the handling and transfer of packages by an EVA crewman such as individual crewman strength, mobility aids, package mass and shape, transfer velocity and spacecraft perturbations. Variables such as crewman strength and spacecraft perturbations can only be controlled within certain limits. However, several factors can be considered in package design that will improve EVA support capability. The package size should not limit the crewman's visibility during transfer, particularly for one-man handling. Simulations have shown that packages with 1.0 by 0.76 meter (40 by 30 in.) frontal dimension can be transported by one man with no significant visual problems. The maximum mass that can be safely handled by EVA crewmen has yet to be established; however, simulations have demonstrated that two crewmen can satisfactorily handle 3825 kg. (8500 lbs.). Comments by subjects during the simulations indicate that masses 2 or 3 times greater might also be safely transported.

Other considerations in package design are the location of handholds on the package with respect to its center of mass and the number of crewmen involved in the transfer. The moment of inertia about the package handle is often the limiting factor in "controlled" transfer of a package.

2.2.5.3 Translation and Work Envelopes

The dimensions of the EMU dictate a minimum unrestricted 1.0 meter (40 in.) diameter for all translation corridors and openings when performing EVA tasks (see Figure 2.2-13). The translation corridors and work stations must either be free or protected from sharp edges and corners to prevent damage to the crewman and EMU. For adequate visibility, lighting along translation routes must be greater than 1 foot lambert and be equal to, or greater than, 5 foot lamberts at the worksite.

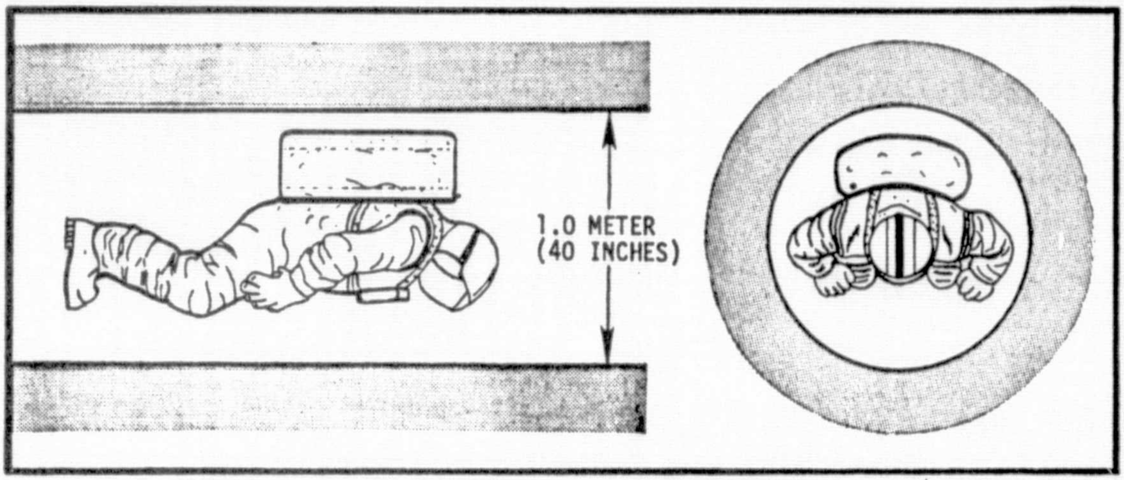


FIGURE 2.2-13: Minimum Unrestricted Translation Corridor

In addition to the reach and mobility of a suited crewman discussed previously, several other design factors must be considered at the EVA worksite. A suited crewman can perform most of the manipulative tasks that a shirtsleeved person can perform if adequate consideration is given to the space and volume requirements of gloved hand operations.

Figure 2.2-14 shows the minimum work envelope required for a gloved hand working between boxes or structures.

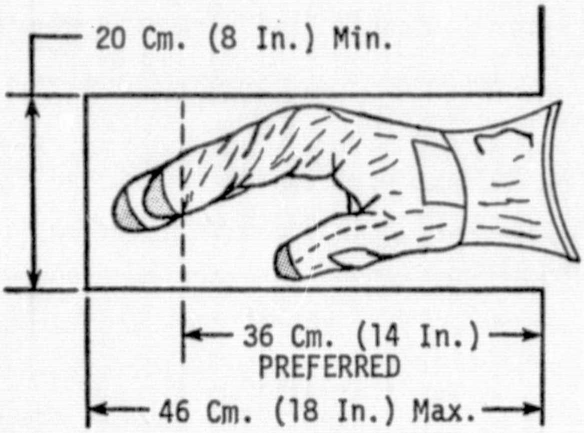


FIGURE 2.2-14: Minimum Work Envelope For Gloved Hand

Note that while reaching into depths of 46 cm. (18 in.) is acceptable, a 36 cm. (14 in.) depth is preferred. If connectors, valves, and similar devices are to be operated, the work envelope must be enlarged. In the case of equipment such as multiple connectors that require alignment and locking, a minimum separation of 2.54 cm. (1 in.) between connectors is required with 4.1 cm. (1.6 in.) or more preferred.

2.2.5.4 Operating Forces

The strength capabilities of suited crewmembers are comparable to their shirtsleeve capabilities. However, for "zero-gravity" operations, handles, doors, fasteners, and other equipment routinely operated by an EVA crewman should have actuation forces less than 15.8 kg. (35 lbs.). A 4.5 kg. (10 lb.) force is preferred. In considering minimum forces, the force should be sufficient to provide the suited crewman with adequate feedback to indicate operational status and counteract the diminished tactility due to the EVA glove.

2.2.5.5 Temperature

Surfaces and equipment that an EVA crewman may contact must have finishes that ensure the temperatures do not exceed -117.8^{o}C to +93.3^{o}C (-180^{o}F to +200^{o}F). The EV gloves are designed to protect the crewman's hands at these temperature limits based on a contact pressure of 0.14 kg/cm^2 (2 psi) for 2 minutes. As the temperature is reduced, the contact pressure and duration may increase.

2.2.5.6 Controls and Displays

EVA controls and displays should be limited to only those required to complete the EVA task. Checkout, trouble-shooting, and similar operations should be performed by a crewman inside the spacecraft.

Relative to the field-of-view from the EMU, controls or equipment requiring visual alignment should be located within 28.7 degrees of the normal line-of-site in the vertical plane and 57.3 degrees in the horizontal plane. To prevent accidental operation, damage to the panel, or injury to the crewman, the controls should be protected either by barrier guards or by being recessed in the panels. To reiterate, because of the reduced tactile feedback through the EV gloves, flags, lights, or mechanical feedback sufficient to override glove attenuation should be used to give the crewman positive indication that the task is complete. For example, push button, rocker and rotary switches should be avoided for EVA operations; toggle switches are preferred.

2.2.5.7 General EVA Safety

The EMU and crewman must be protected from sharp edges, burrs, protrusions, thermal extremes, etc. to avoid suit damage or crew injury. Radiological, electrical, electromagnetic, and pyrotechnic equipment safety relative to EVA operations must also be considered. The design should incorporate safety requirements to preclude hazards to personnel and equipment in accordance with the Space Shuttle Program provisions established in Reference 2.2.1.

SECTION 2.2 REFERENCES

REFERENCE

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2.2.4 NASA: Man-System Design Criteria for Manned Orbiting Payloads, MSFC-STD-512.

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2.3 REMOTE MANIPULATOR SYSTEM

2.3.1 Introduction

Provisions for Orbiter-attached manipulator systems are available on each Shuttle flight. The systems are specifically designed for payload and cargo handling, vehicle inspection, equipment monitoring, and to perform crew-member rescue operations from a disabled Orbiter, should conditions warrant. However, the manipulator system may be used to support payload EVA operations when equipped with extravehicular supporting subsystems. The current Shuttle baseline Remote Manipulator System (RMS) consists of one manipulator arm mounted on the port (left) longeron in the payload bay, mounting provisions for an additional arm on the starboard (right) longeron, and a control system located in the Orbiter cabin (Figure 2.3-1). The Orbiter provides one complete RMS on each Shuttle flight; the second manipulator arm is weight chargeable to the payload. An RMS control system with appropriate interfaces on each longeron is provided. The manipulator arms can be operated sequentially but not simultaneously. Both manipulator arms may be removed if not required for a particular flight.

2.3.2 RMS Basic Design Functions

The RMS design charter is to provide a system capable of performing the following Orbiter and payload operations:

- Remove the payloads listed in Figure 2.3-2 from the payload bay and deploy the payloads to a stabilized condition
- Attach to free-flying, stabilized payloads and transport the payloads into position for securing in the payload bay
- In a rescue capacity, transport an EVA crewman (in an EMU or PRS) from a disabled Orbiter side access hatch or airlock area and position the crewman at the airlock of the rescue Orbiter
- Perform other tasks secondary or compatible to the above.

Although the Shuttle RMS primary design objective is to satisfy the

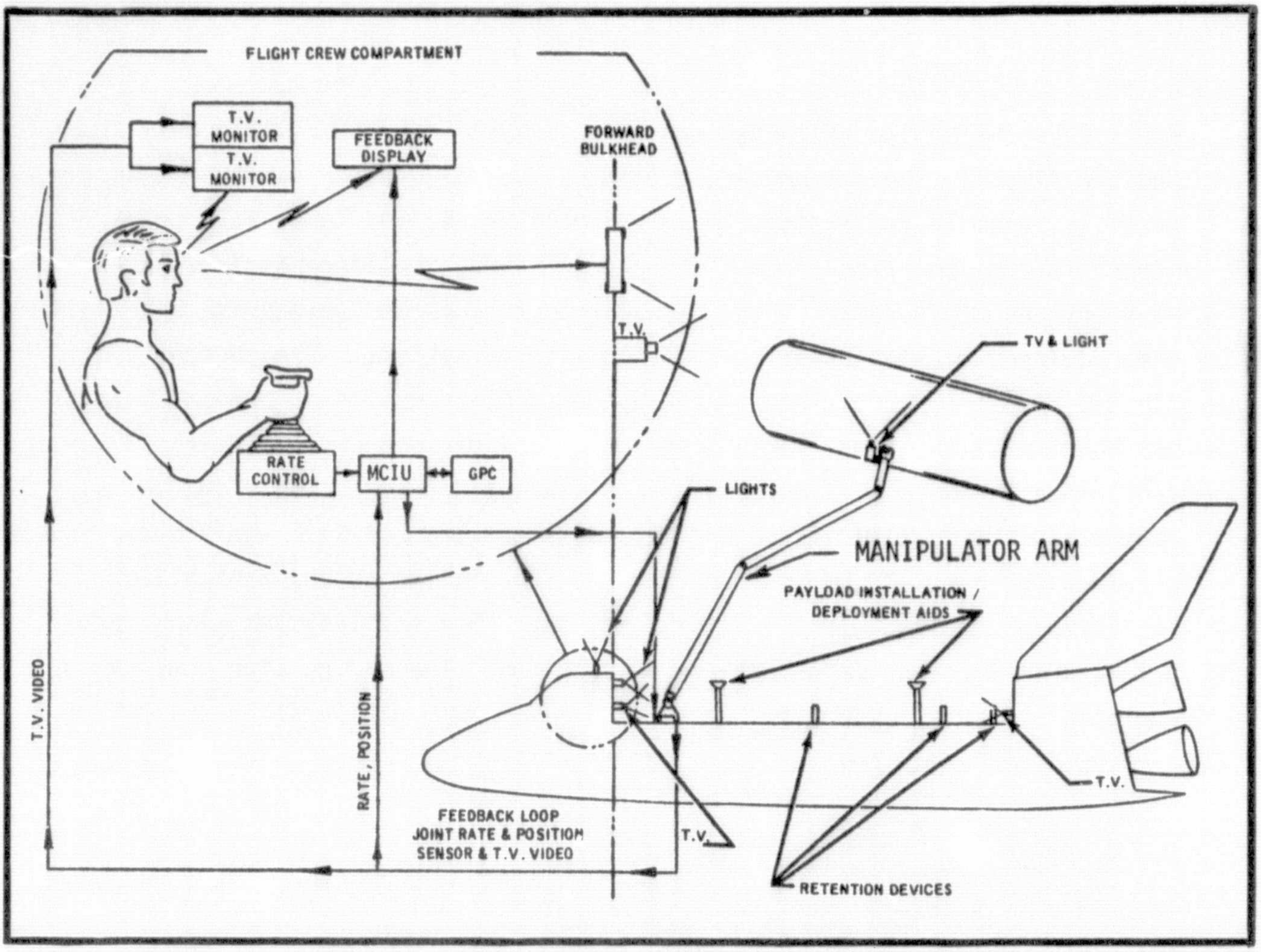


FIGURE 2.3-1: Shuttle Baseline Remote Manipulator System

requirements listed above, the system is capable of performing diverse payload EVA support functions, particularly cargo/module handling and providing extravehicular translation routes and crewman stabilization/ restraint at the worksites (see Section 2.7). The RMS also has the capability to perform payload servicing operations requiring manipulative tasks while the payload is attached to the Orbiter. Representative RMS servicing tasks may include deploying antennas and solar arrays, removing protective covers, replacing modules and positioning sensors and cameras

for data acquisitioning/ monitoring.

2.3.3 Systems Description

The Orbiter RMS baseline configuration and general capabilities are described in the following subsections. Only an overview of the major design characteristics is presented for payload planning relative to EVA servicing applications. Detail design information may be acquired from References 2.3.1 through 2.3.5.

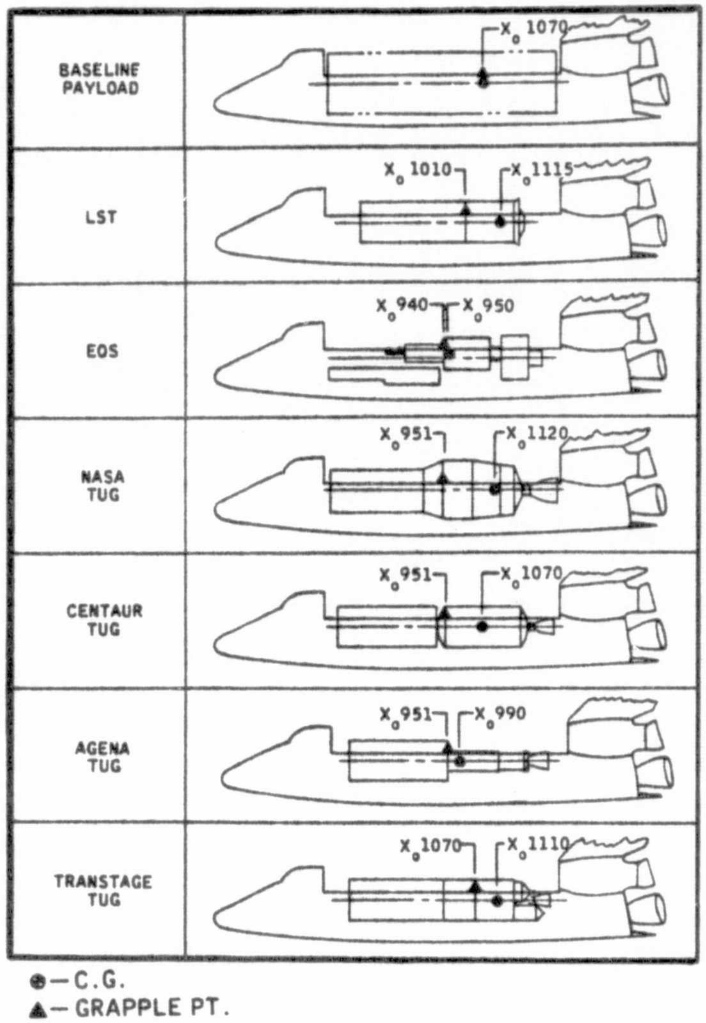


FIGURE 2.3-2: Baseline Payloads for RMS Functional Design

2.3.3.1 Manipulator Arm

The manipulator arm is a 15.3 m. (50 ft.) long, 0.3 m. (12 in.) diameter tubular structure consisting of upper and lower arms, wrist assembly and end effector (Figure 2.3-3). Both the upper and lower arms are 6.9 m. (264.5 in.) long between pitch joints. The wrist assembly in 1.8 m. (71.0 in.) from the pitch joint to the tip of the end effector. Six joints provide six degrees of freedom for handling payloads and cargo in a zero-gravity environment only. The manipulator arm geometry is shown in Figure 2.3-4. The Orbiter baseline manipulator arm is attached to the minus Y (port) longeron at station X_o679.5 and extends to within .55 m. (21.5 in.) of the aft bulkhead at station X_o1307. The joints are actuated and braked by electromechanical subsystems.

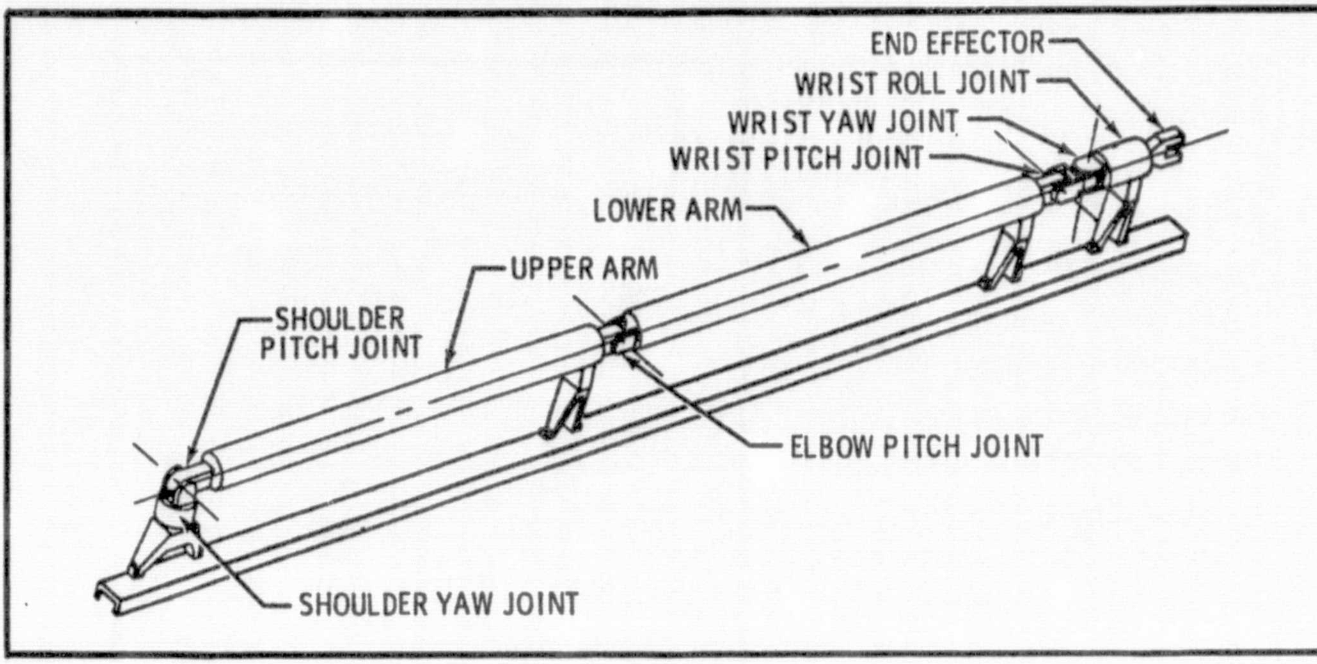


FIGURE 2.3-3: RMS Baseline Configuration

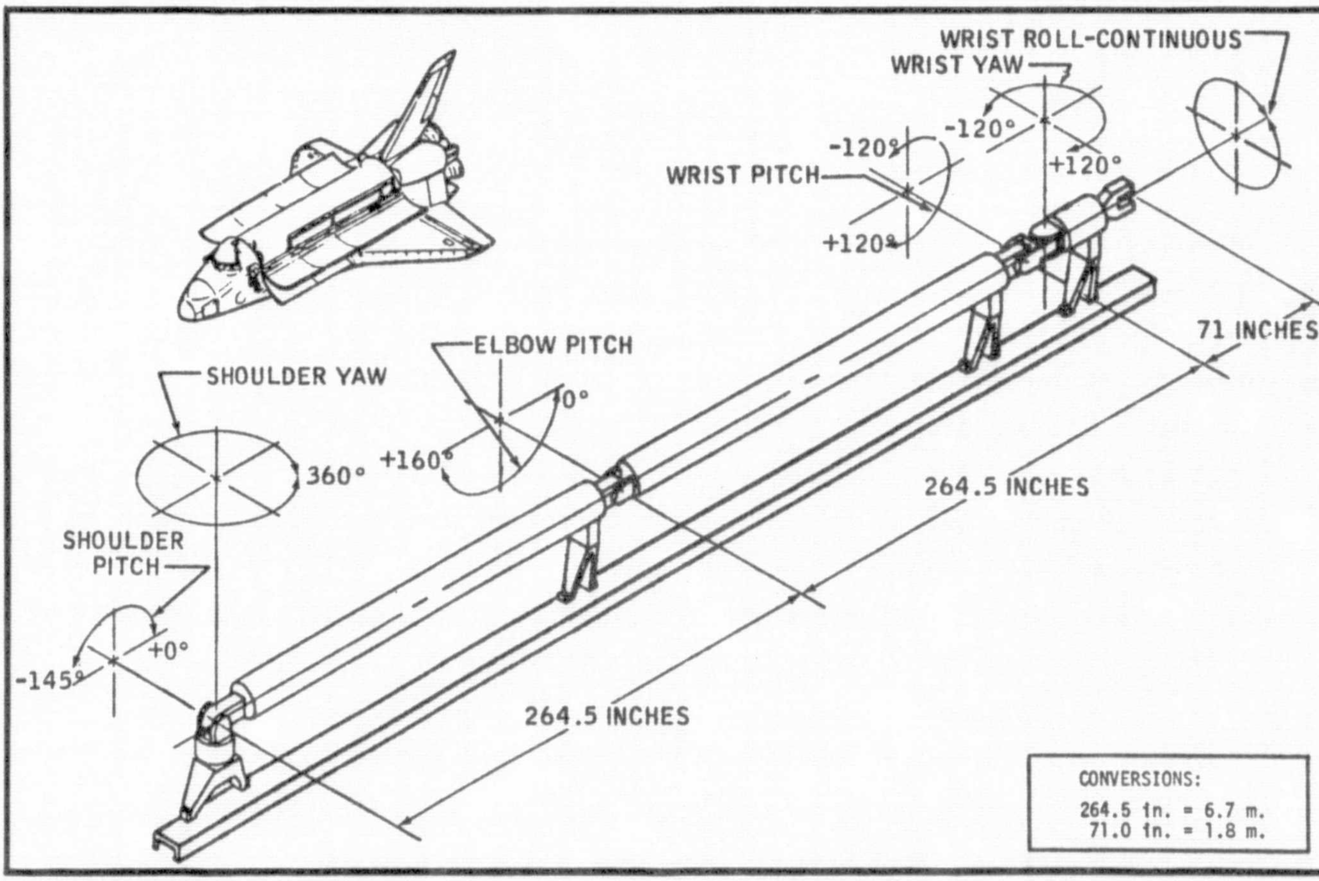


FIGURE 2.3-4: RMS Joint Movements

The manipulator arm is stowed in the payload bay outside the payload envelope. A deployment/retention subsystem deploys the arm from the stowed position to provide payload/manipulator clearance during payload handling (Figure 2.3-5). Retention fittings are located at X_o679.5, X_o911.05, X_o1153.5 and X_o1256.5 for securing the arm when not in use. Should RMS failure occur in an unstowed position, a separation system is provided at each retention location. The separation system allows jettison of the RMS arm for payload bay door closure without impact or damage to the Orbiter or payloads.

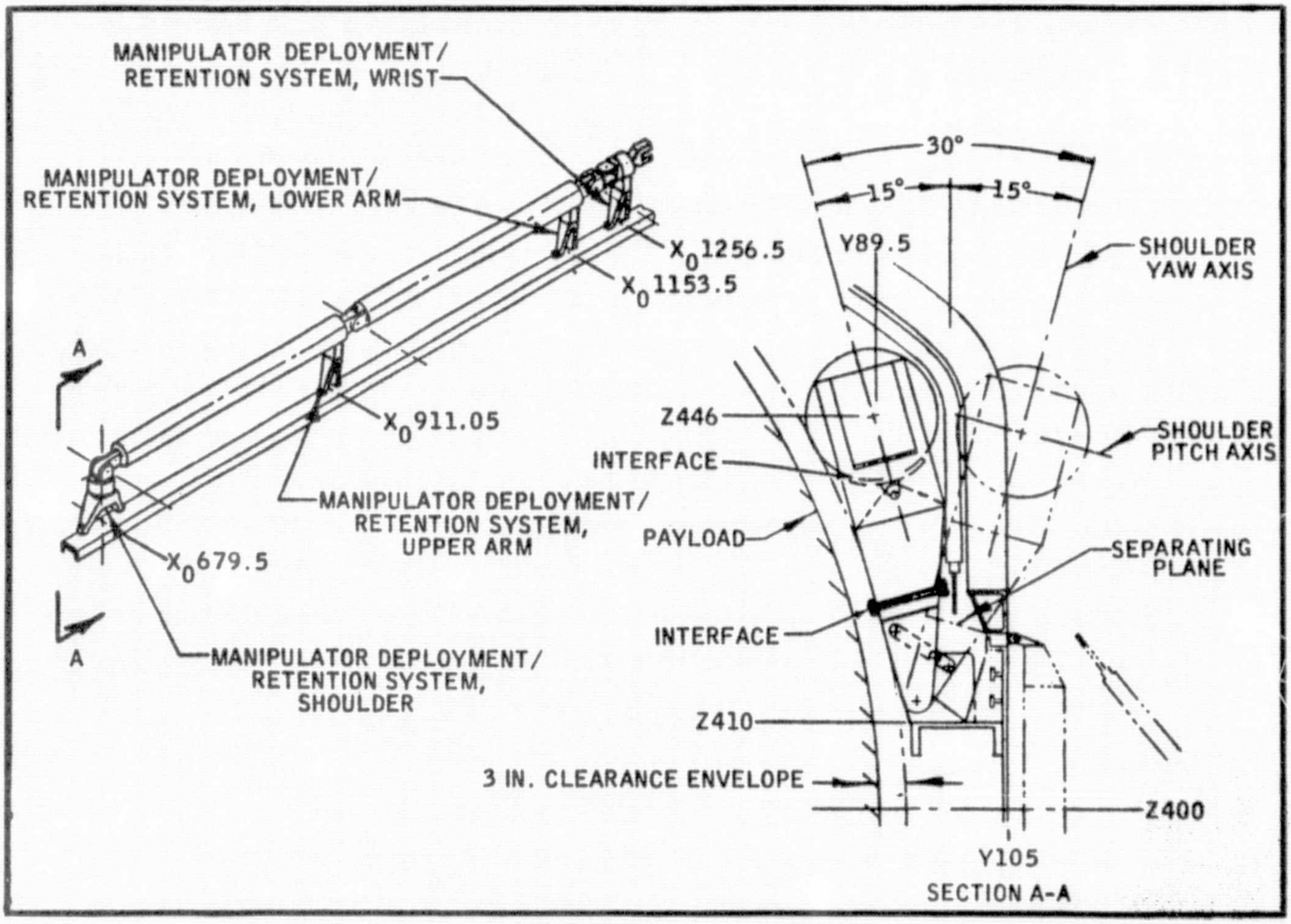


FIGURE 2.3-5: RMS Deployment/Retention System

The RMS end effector performs the mechanical coupling between the manipulator arm and the payload/cargo. The end effector(s) attaches to the manipulator wrist and interfaces with a passive payload/cargo fixture. A standard end effector is provided for payload handling tasks with the capability to exchange end effectors in flight without EVA. An end effector concept is shown in Figure 2.3-6 for payload application. The end effector is designed to attach to a payload/cargo fixture with an initial linear misalignment of $\pm$10.2 cm. ($\pm$4.0 in.) in the X, Y, and Z axes and an angular misalignment of $\pm$15° in roll, pitch, and yaw. The mechanical interface after coupling is designed to react a minimum of 1.5 times the maximum load which the RMS can induce. The structural deflection of the end effector or attachment fixture when subjected to maximum load is designed not to exceed 0.15 degrees in pitch, roll, and yaw, and 0.25 cm. (0.1 in.) in the X, Y, and Z axes.

Payload Installation and Deployment Aids (PIDA) are provided to assist payload handling and avoid impact damage to the Orbiter or payloads. The aids (Figure 2.3-7) are used primarily for installing 4.6 m. (15.0 ft.) diameter payloads. The manipulator arm structural deflection and visibility restrictions while handling large massive payloads present a risk in attempting to position the payloads within the $\pm$7.6 cm. ($\pm$3.0 in.) Orbiter payload bay clearance envelope (ref. Figure 2.3-6). In using the payload installation aids, the RMS sequentially positions the probe fittings into the drogue sockets. The PIDA then rotate the payload into the proper retention fittings, and the payload is secured. The drogue sockets are designed for $\pm$15.2 cm. ($\pm$6.0 in.) lateral misalignment and $\pm$15 degrees angular misalignment at each point. The payload installation aids also have the potential capability to stabilize a payload for RMS/EVA on-orbit servicing.

2.3.3.2 Force, Arm Speed and Deflection

The manipulator can exert a 6.8 kg. (15 lbs.) tip force when the arm is fully extended. Forces in excess of 23 kg. (50 lbs.) can be applied dependent upon arm joint position/attitude. Manipulator force capability curves depicting available force at the end effector, perpendicular to the

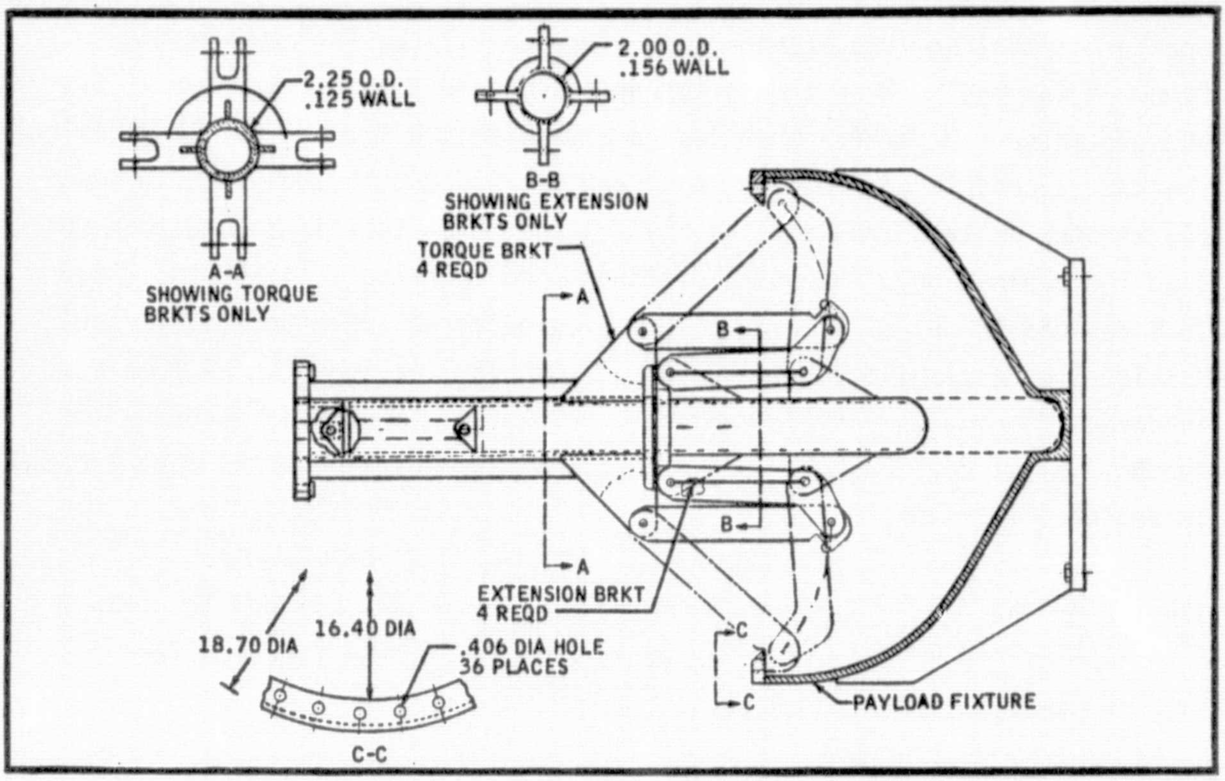


FIGURE 2.3-6: RMS End Effector Concept

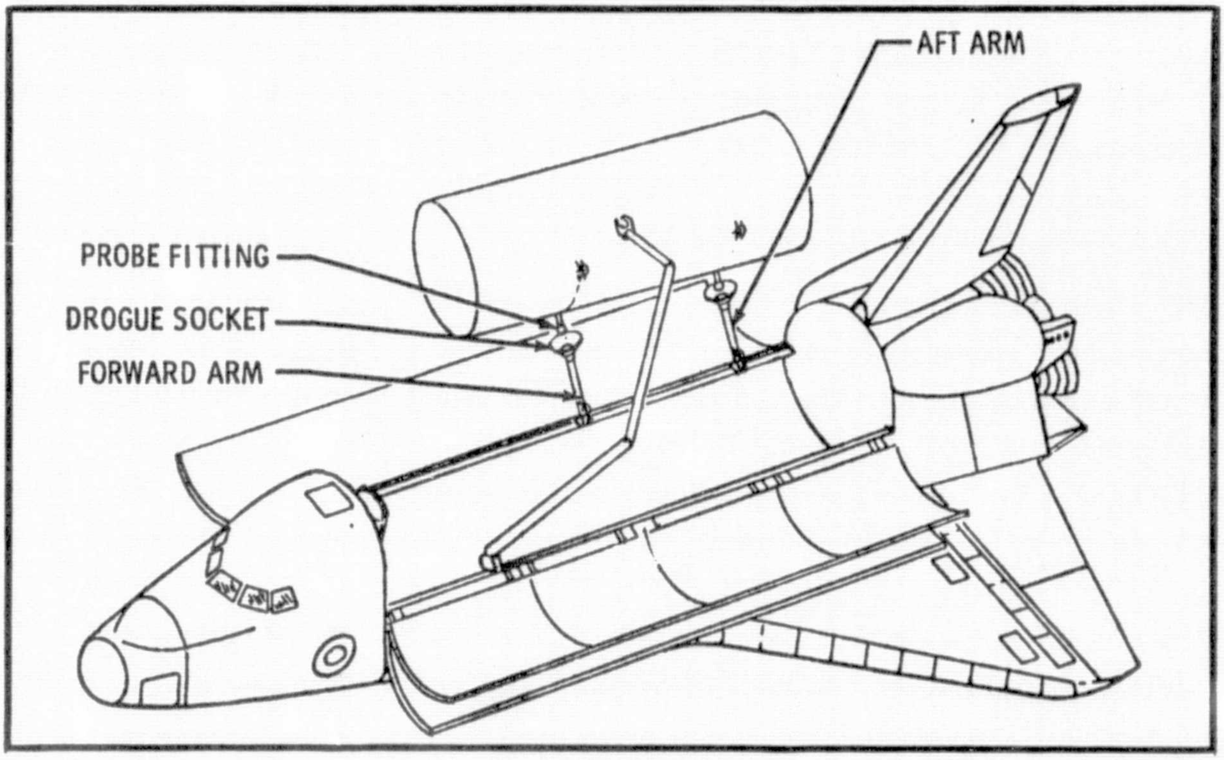


FIGURE 2.3-7: Payload Installation/Deployment Aids

Orbiter centerline, are provided in Reference 2.3-1. The maximum tip speed of the manipulator arm in the unloaded condition is .6 m/sec (2.0 ft/sec) and .06 m/sec (.2 ft/sec) when loaded with a 29,510 kg. (65,000 lb.) payload. The RMS is capable of deploying a 14,530 kg. (32,000 lb.) payload in seven (7) minutes or less from payload bay release to a stabilized condition outside the payload bay. Stopping distance when handling a 14,530 kg. (32,000 lb.) payload is .61 m. (2.0 ft.) from a velocity of .06 m/sec (.2 ft/sec). Retrieval of a stabilized 11,350 kg. (25,000 lb.) payload can be completed in seven (7) minutes or less from initial capture to payload securing in the bay. Time required for each manipulator arm joint movement (joint rate) is depicted in Figure 2.3-8.

The tip of the manipulator arm at the end effector is designed to deflect a maximum of .56 cm. per kilogram of force (.10 in. per pound of force) with the arm in the extended position.

2.3.3.3 Manipulator Reach

The reach capabilities of the manipulator arm inside the payload bay envelope and outside the Orbiter vehicle are shown in Figures 2.3-9 and 2.3-10, respectively. Detailed manipulator reach and viewing capabilities are provided in Reference 2.3-3.

2.3.3.4 Manipulator Lighting and Viewing

RMS lighting is provided for direct and TV viewing to perform required manipulator operations. One light is provided on the manipulator arm wrist assembly, one on the top of the Orbiter cabin near the forward bulkhead, and another mounted directly on the forward bulkhead. Six lights are located in the payload bay: three on each side. The light on the top of the cabin (forward and between the two overhead windows) provides illumination primarily for initial payload capture and retrieval. The remaining lights provide illunination for performing manipulator and payload operations either by direct vision or TV monitor when natural light is blocked from the Orbiter.

SPACE SHUTTLE EVA

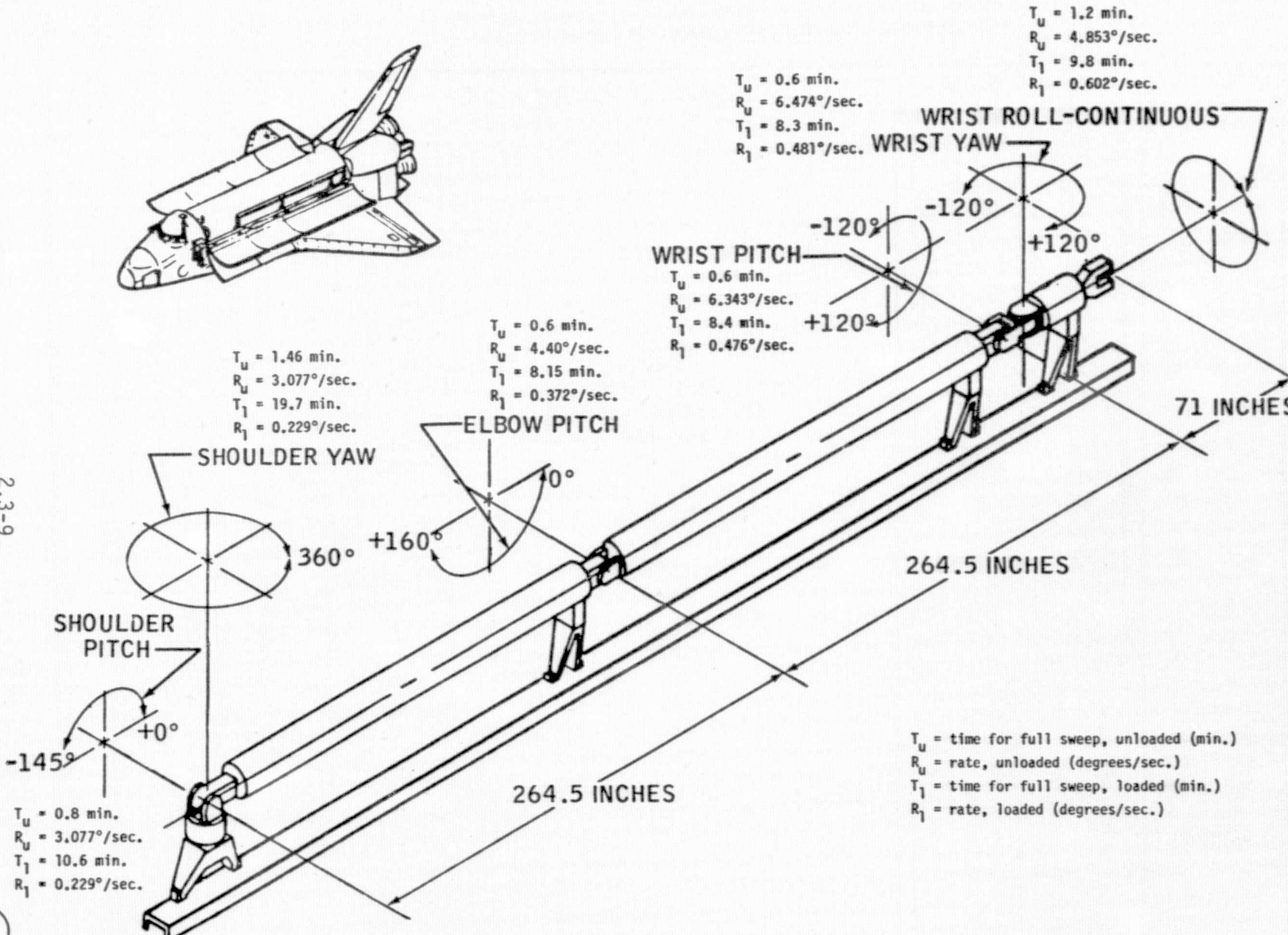


FIGURE 2.3-8: Manipulator Arm Joint Movement Characteristics

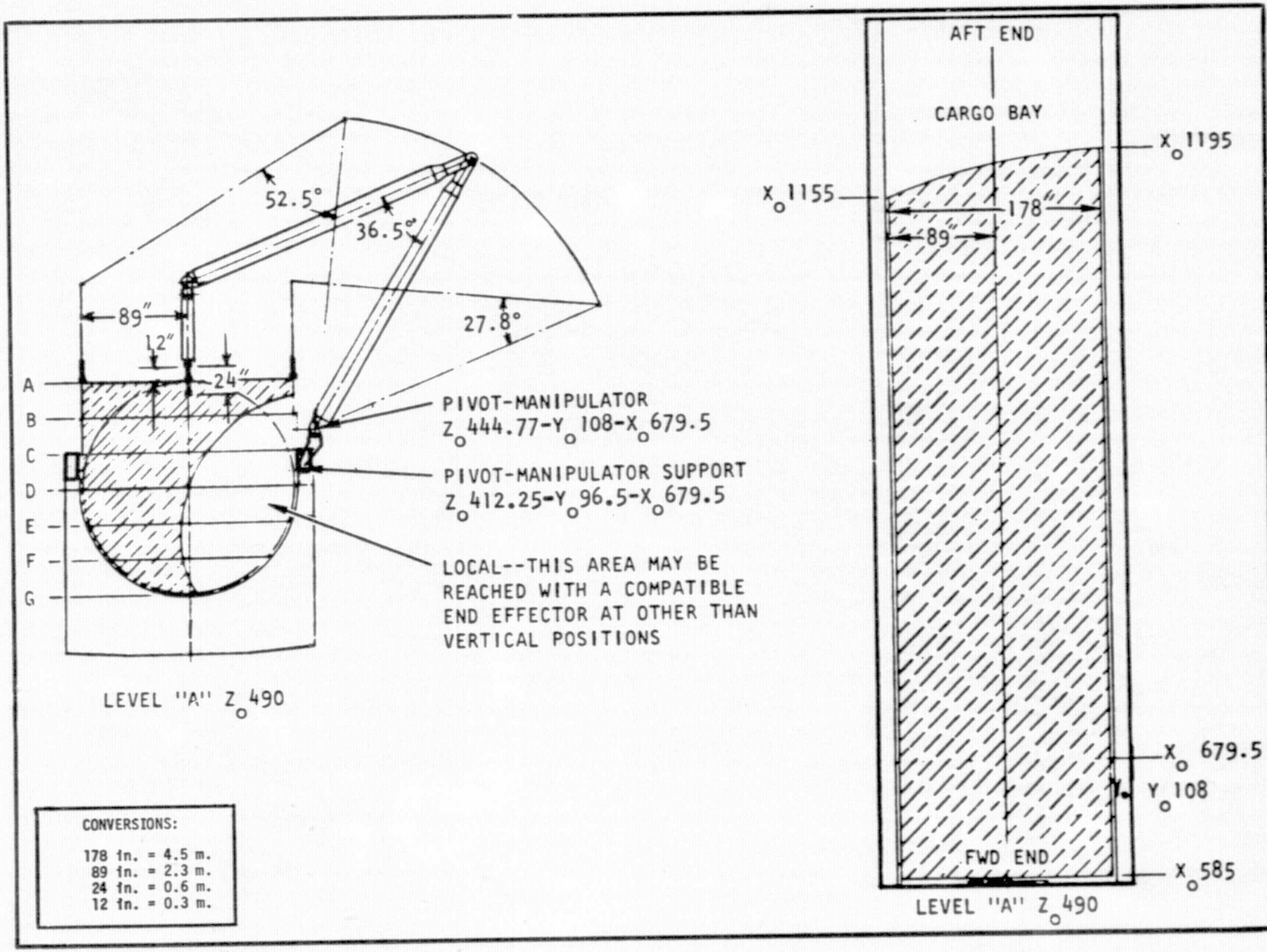


FIGURE 2.3-9: Manipulator Reach Inside Payload Bay

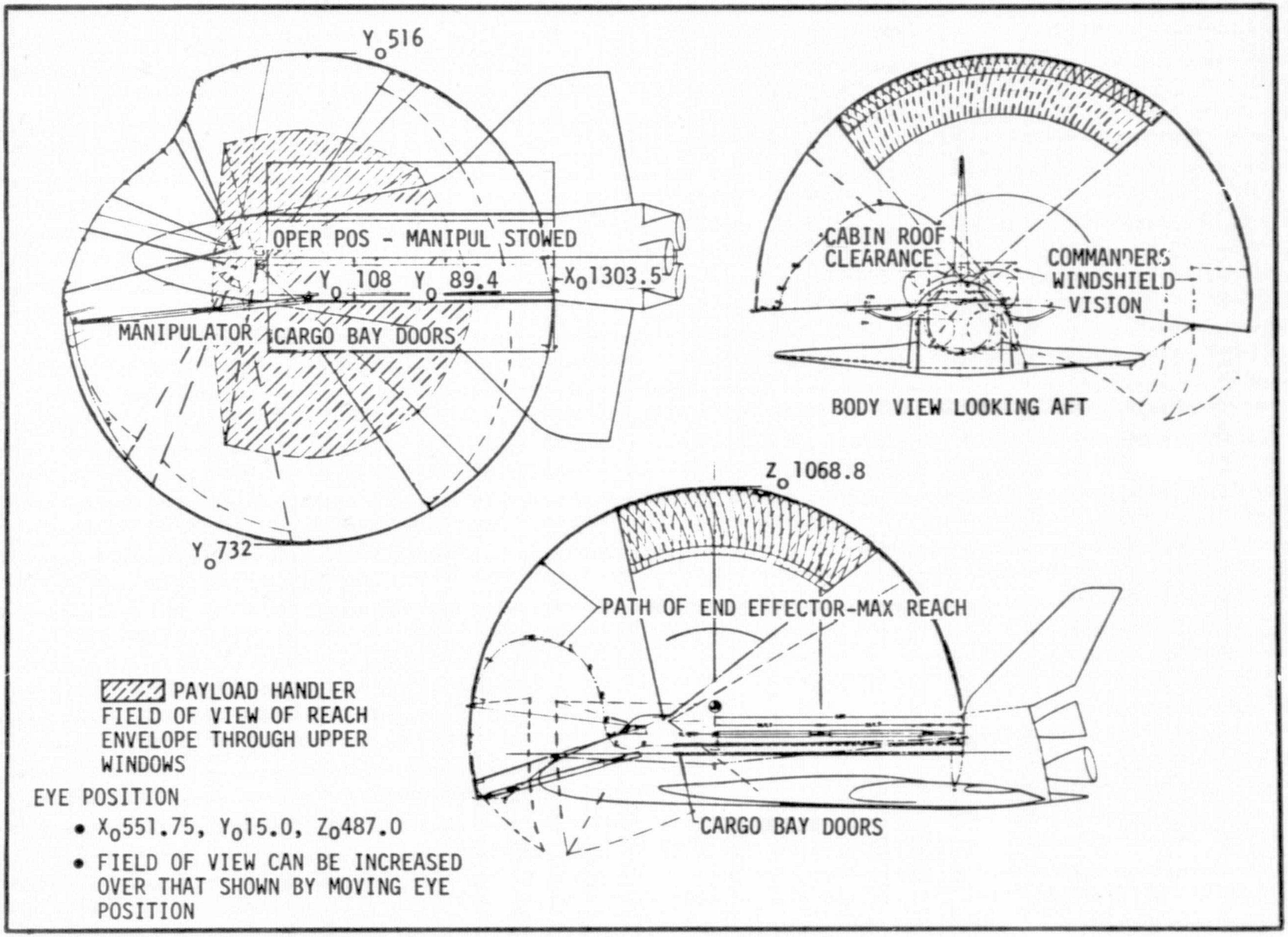


FIGURE 2.3-10: Manipulator Reach Outside Payload Bay

The lighting system is designated as follows (ref. Figure 2.3-1):

- Payload Bay Light (6 each)
- TV Viewing Light (manipulator mounted)
- Payload Manipulator Light (forward bulkhead mounted)
- Payload/Docking Light (top of Orbiter cabin).

The payload bay lights provide a minimum intensity of 10 foot lamberts throughout the payload bay. The TV viewing light intensity provides five foot candles illumination on an object at a distance of 18.3 m. (60 ft.) from the light source. Full illumination in the payload bay and transition areas is provided by the payload manipulator light; the payload bay/docking light is capable of providing 5 foot lamberts illumination on a payload approximately 18.3 m. (60 ft.) from the Orbiter cabin overhead windows. On-off controls are provided for independent operation of each light.

A closed circuit television system provides visual information to the RMS operator to supplement direct vision. Two TV cameras are mounted in the payload bay--one near each bulkhead. A third TV camera is installed on the manipulator arm assembly. Each camera has remote control features for pointing and zoom. Two monitors with split screen capability are located at the RMS operator's station inside the cabin (ref. Figure 2.3-1).

2.3.3.5 Manipulator Operation

The Shuttle manipulator system is designed for one-man, shirtsleeve operation from a standup (foot-restrained) location at the Orbiter cabin RMS workstation. A conceptual layout of the workstation subsystem location and panel geometry, used in design/simulation activities during system development, is shown in Figure 2.3-11. The layout approximates the baseline RMS components, location and configuration.

The RMS operator has the capability to direct the control of the system throughout all operational modes. Three manipulator arm guidance and control

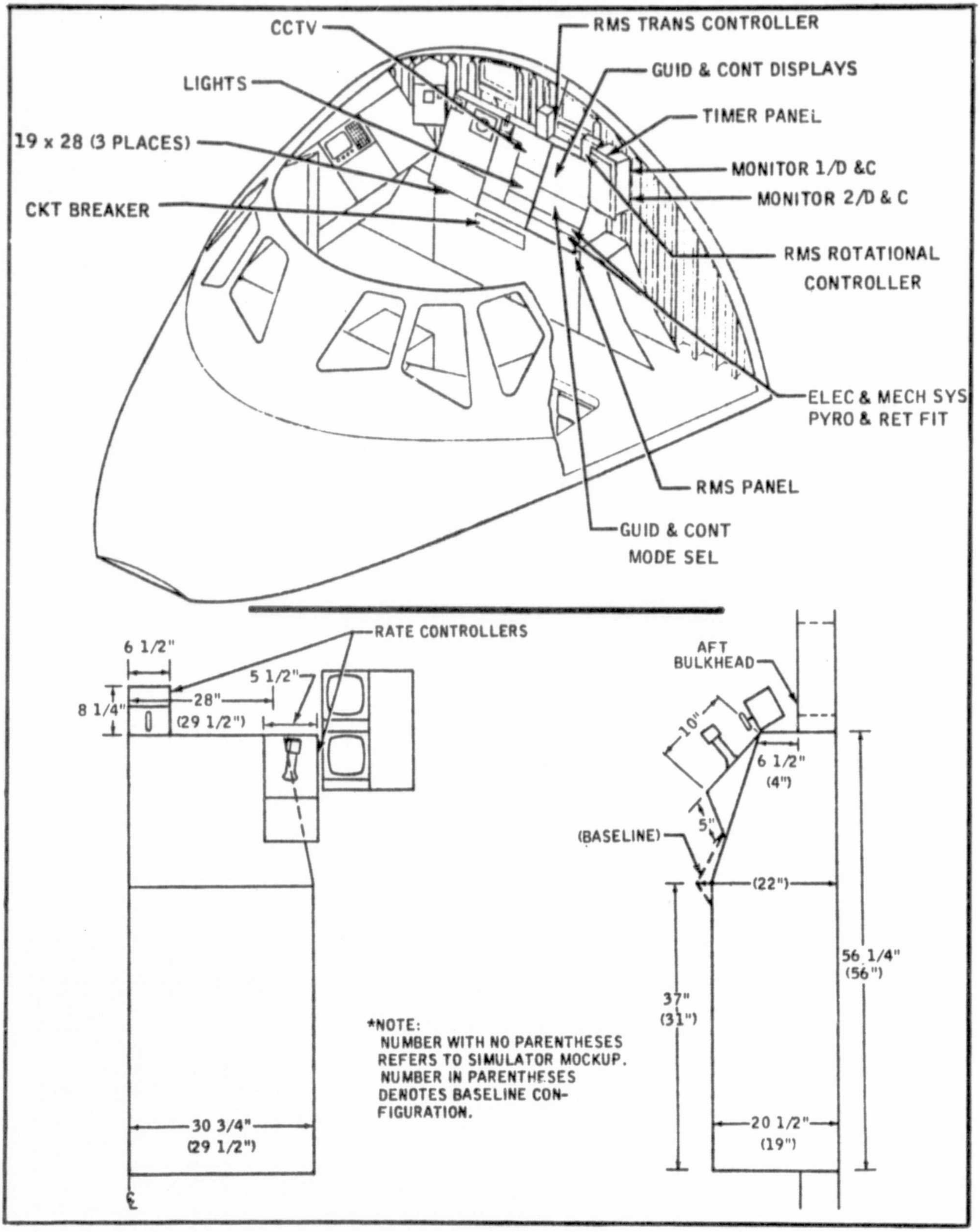


FIGURE 2.3-11: Control System Layout Concept

modes are available:

- Automatic preprogrammed control
- Manual augmented control
- Backup direct drive control.

The automated and manual augmented control modes are capable of operating in any one of three coordinate systems: Orbiter referenced, payload referenced, or end effector referenced.

The manipulator control system is designed to deploy/release a payload within the following limits using the Orbiter guidance and navigation inertial platform as a reference:

- Attitude error: 15°
- Linear tip-off motion: 6.1 cm/sec (0.2 ft/sec)
- Angular tip-off motion: 0.04°/sec.

In capturing a free-flying satellite, the payload must maintain the following stabilized conditions:

- Attitude rates: ±0.1 degree/sec., maximum
- Attitude hold resulting in a ±7.6 cm. (±3.0 in.) or less motion of the payload interface fixture.

2.3.3.6 Manipulator Arm Weight

Flight qualified RMS weights were not available during development of this report; however, control weights are assigned for all RMS items located in the payload bay and crew cabin. The NASA specified control weights (i.e., maximum) are shown in Table 2.3.1. The optional second manipulator arm is weight chargeable to the payload.

TABLE 2.3.1: NASA RMS Control Weight -- Preliminary

FUNCTIONAL ITEM	CONCEPT BASELINE		SECOND ARM	
	kg.	lb.	kg.	lb.
Manipulator Arm	245	540	245	540
Manipulator Deploy and Retention	112	247	112	247
Manipulator Support and Installation	33	73	33	73
Electrical Installation	12	26	6	14
Avionics Installation	32	71	12	27
Payload Installation and Deployment Aid	113	250	N/A	N/A
Margin	30	66	30	66
Total Weight	577	1273	432	967

2.3.4 EVA Provisions

The RMS will provide EVA translation routes and mobility aids via the manipulator arm assembly. Handrails may be installed on the arm prior to launch for access to berthed payloads or areas outside the payload bay. The arm, with appropriate end effectors, may provide portable workstation restraint at EVA worksites and cargo handling. Rescue capability includes transfer of EVA crewmembers and equipment between orbiting vehicles when the crew is equipped with space suits or self-contained EVA rescue systems. The extent of RMS support to payload EVA operations will be further defined as payload and experiment development progresses.

2.3.5 RMS Characteristics Summary

The major physical and operational characteristics of the Remote Manipulator System are summarized in Table 2.3.2 as a convenient reference for the reader.

TABLE 2.3.2: RMS Characteristics Summary

RMS SYSTEM/COMPONENT	CHARACTERISTICS	REMARKS
Manipulator Arm Length	15.3 m. (50 ft.)	3 sections
Mounting Location	Station X_o697.5 on -Y (port) longeron	Major retention fitting in payload bay
End Effector • Payload attachment tolerance/capability	Linear misalignment: $\pm$10.2 cm. ($\pm$4.0 in.) in the X, Y, and Z axes; Angular misalignment: $\pm$15° in roll, pitch, and yaw	Interchangeable on-orbit
Payload Installation and Deployment Aid (PIDA) • Drogue socket capture tolerance	Lateral misalignment: $\pm$15.2 cm. ($\pm$6.0 in.) Angular misalignment: $\pm$15°	Assist in handling large payloads
Manipulator Arm Force	• 6.8 kg. (15 lbs.) tip force • 23 kg. (50 lbs.)	Arm fully extended Arm position/attitude dependent

TABLE 2.3.2: RMS Characteristics Summary (continued)

RMS SYSTEM/COMPONENT	CHARACTERISTICS	REMARKS
Arm Tip Speed	• Loaded: .06 m/sec (.2 ft/sec) • Unloaded: .6 m/sec (2 ft/sec)	Load = 29,500 kg. (65,000 lb.) payload
Arm Stopping Distance	• Loaded: .6 m. (2.0 ft.)	Load = 11,350 kg. (32,000 lbs.) at a velocity of .06 m/sec (.2 ft/sec)
Manipulator Control System Operation	• Attitude error: 15° • Linear tip-off motion: .06 m/sec (0.2 ft/sec) • Angular tip-off motion: 0.04°/sec • Attitude rates: ±0.1°/sec • Attitude hold: ±7.6 cm. (±3.0 in.) motion of payload interface fixture	Manipulator deploys/releases payload within these limits Satellite must maintain these conditions for RMS capture
RMS Weight (Total)	430 kg. (957 lbs.)	Excluding PIDA
Manipulator Arm Weight	243 kg. (540 lbs.)	50-ft. arm weight only

2.4 AIRLOCK (INTERIOR)

2.4.1 Introduction

The Shuttle internal airlock is located in the aft portion of the Orbiter mid-deck as shown by Figure 2.4-1.

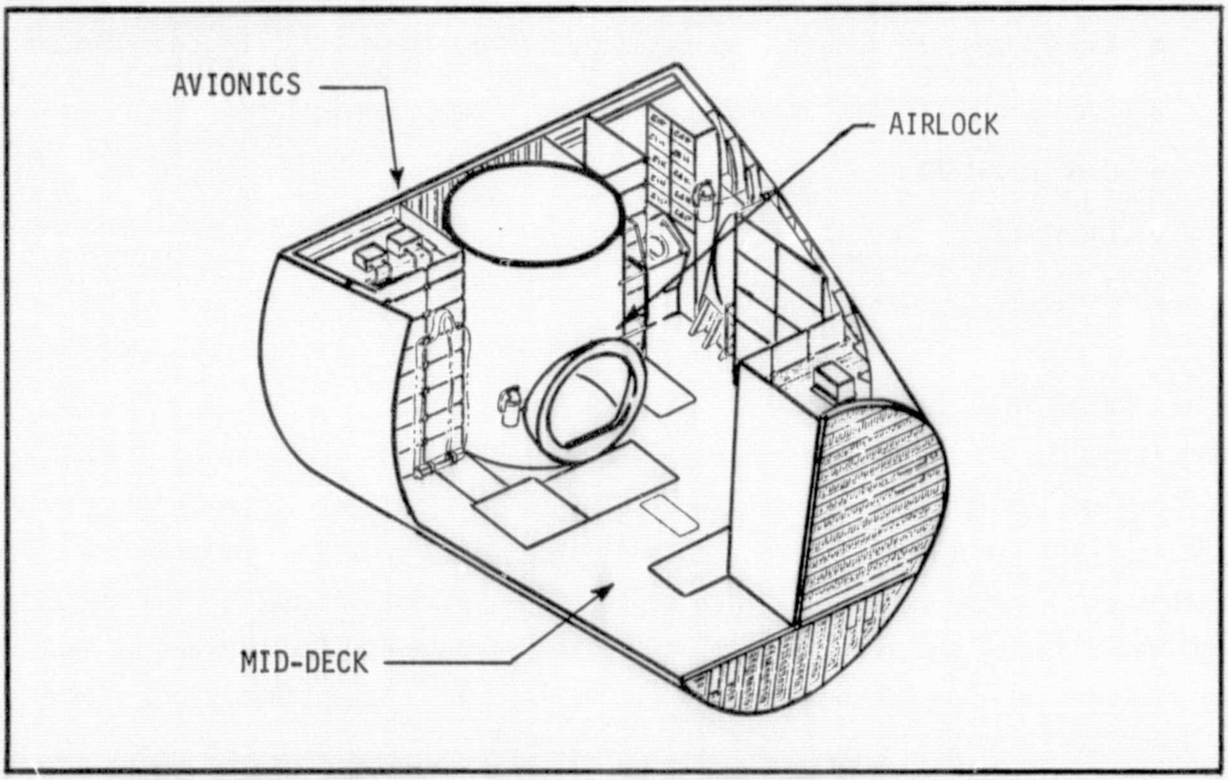


FIGURE 2.4-1: Airlock Located in Shuttle Mid-deck

Two ingress/egress hatches located on the Orbiter vertical centerline at station $Z_0$355 provide a direct EVA path from the mid-deck to the payload bay.

Airlock subsystems provide the following support for EVA:

- Airlock depressurization/repressurization
- Emergency breathing

- Stowage of EVA equipment
- EVA equipment donning/doffing and checkout station
- Handholds and foot restraints
- Vehicle transfer and rescue operations
- Portable life support system recharge provisions
- Liquid cooling loop for spacesuit cooling during pre- and post-EVA periods
- Provisions for astronaut prebreathing (denitrogenization)
- Communications
- Lighting
- Transfer of cargo/experiments.

2.4.2 Basic Airlock Description

The airlock is basically a modular structure 160 cm. (63 in.) inside diameter by 210.8 cm. (83 in.) long, with two 1.0 m. (40 in.) diameter, D-shaped openings [0.91 m. (36 in.) across chorded side], two pressure sealing hatches and a complement of airlock support subsystems. Access to the airlock from the mid-deck and from the airlock to the payload bay is provided by the two pressure sealing hatches located 61 cm. (24 in.) above the airlock floor on opposite sides of the cylinder (Figure 2.4-2).

The airlock configuration provides sufficient volume for a variety of EVA crewman/package combinations for EVA operations. Testing conducted in the NASA/JSC Water Immersion Facility (WIF) and in various mockups/simulators has verified the following crew/cargo combinations for airlock EVA operations:

- One EVA crewman (suited) -- airlock is designed for one-man operation
- Two EVA crewmen
- One EVA crewman with one 76.3 cm. (34 in.) dia. Personnel Rescue System (PRS)
- One EVA crewman with two PRS's

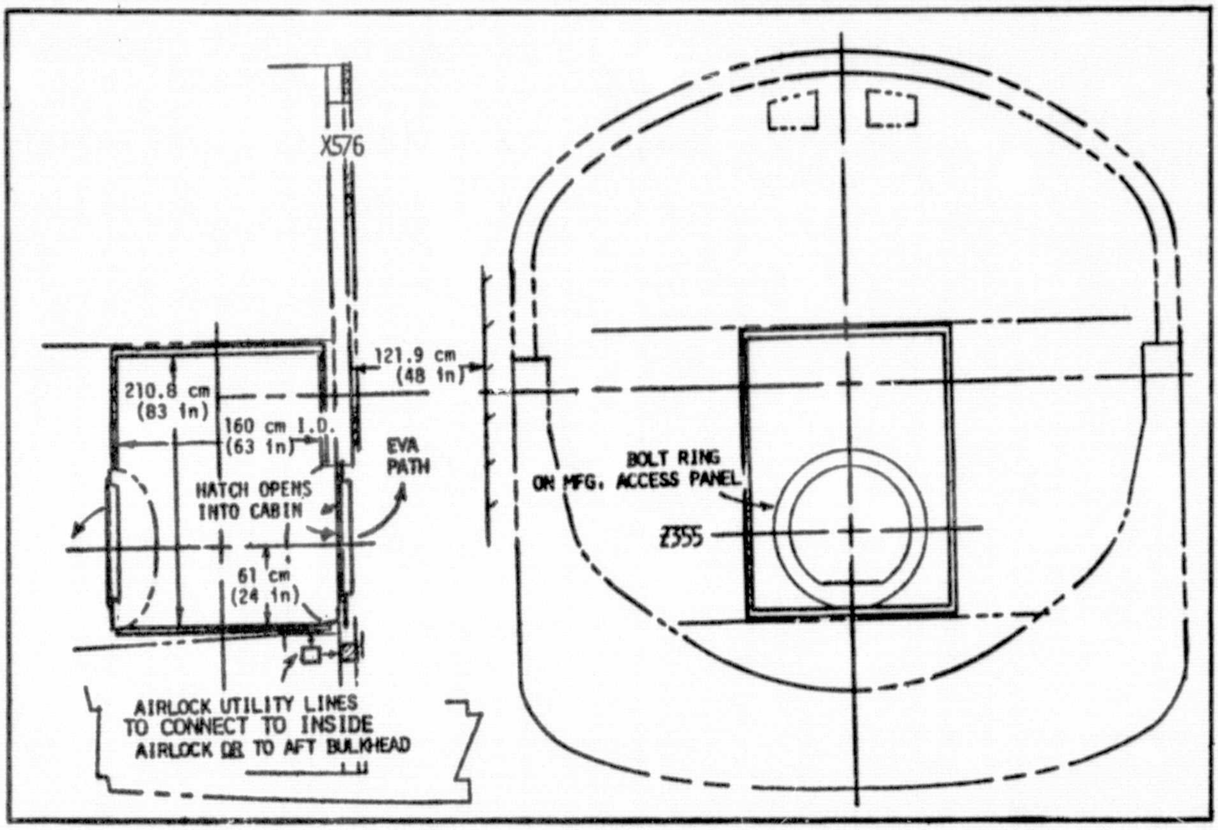


FIGURE 2.4-2: Airlock Configuration

- Two EVA crewmen with two PRS's
- Two EVA crewmen with one PRS
- One EVA crewman with one 45.7 x 45.7 x 132 cm. (18 x 18 x 52 in.) equipment transfer box
- Two EVA crewmen with one 45.7 x 45.7 x 132 cm. (18 x 18 x 52 in.) equipment transfer box.

The airlock is attached to the Orbiter aft (X_o576) bulkhead via bolts to the access panel. The access panel is bolted directly to the aft bulkhead. An interior airlock installation is illustrated in Figure 2.4-3.

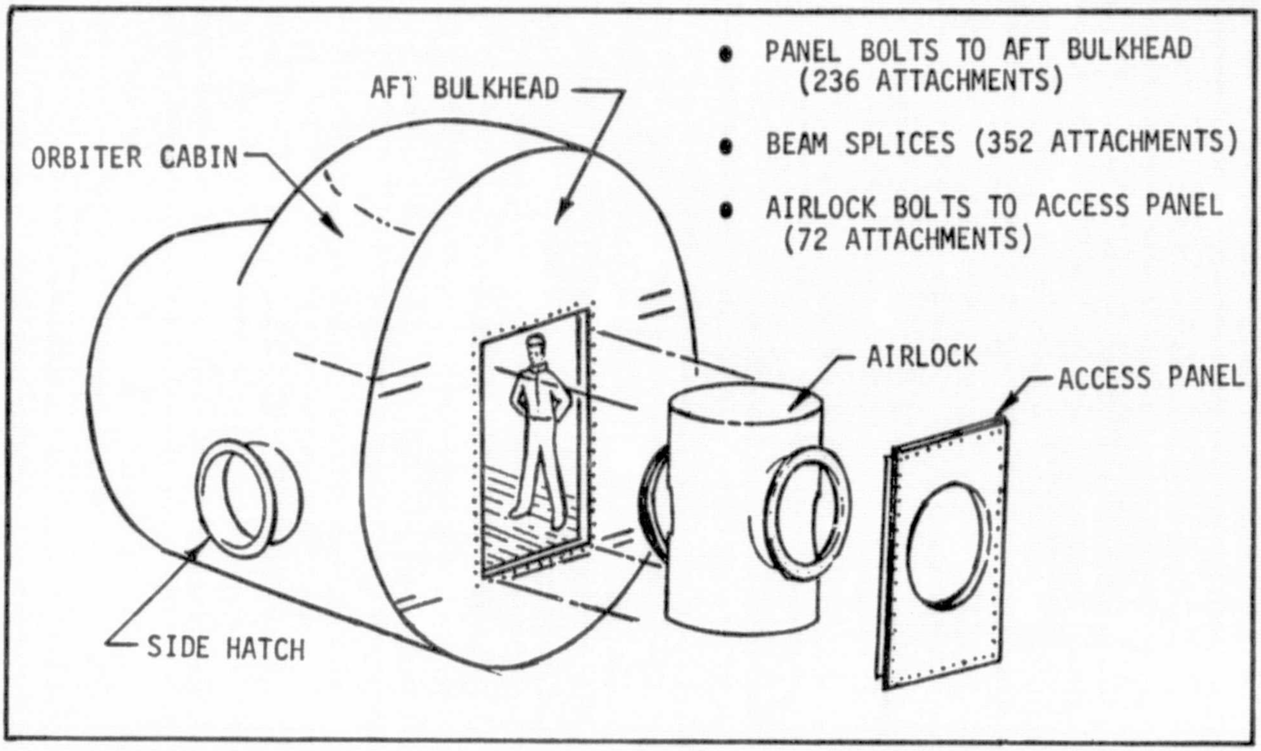


FIGURE 2.4-3: Airlock Interior Installation--Typical

In addition to the interior location in the aft mid-deck area, the airlock is designed for two alternate locations: (1) in the payload bay attached to the cabin aft bulkhead, and (2) in the payload bay on the tunnel adapter (Figure 2.4-4).

The external airlock configuration may be used to provide additional volume in the Orbiter cabin if several crewmen and provisions are required to support payload operations. However, since an EVA egress route for crew rescue must always be provided, manned payloads (Spacelab) cannot use only the external airlock--a tunnel adapter must also be used. The airlock and tunnel adapter combination provides the capability for both pressurized (shirtsleeve) transfer between the Orbiter cabin and manned payloads and

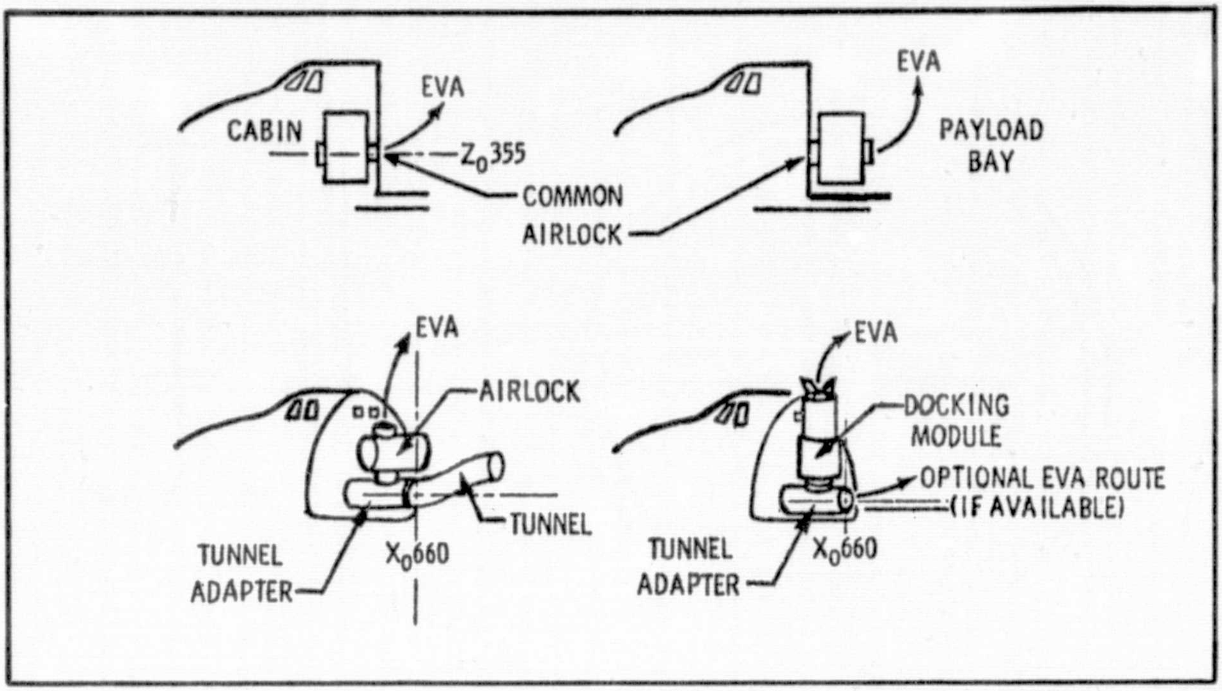


FIGURE 2.4-4: Airlock Multiple Location Capability

suited (EVA) access into the payload bay. EVA can be conducted while the payload is inhabited without interrupting experiment operations. A docking adapter is also available which provides shirtsleeve access to temporarily berthed payloads and between docked Orbiters in special rescue operations. In addition, the docking adapter may be used for suited EVA operations. The external airlock options are discussed in Section 2.5.

The airlock hatches permit EVA crewmembers to exit the Orbiter without depressurizing the Orbiter cabin. While the forward hatch between the mid-deck and the airlock opens into the mid-deck area, the aft hatch between the airlock and the payload bay opens into the airlock. A typical hatch configuration is illustrated in Figure 2.4-5. The aft hatch concept shown in Figure 2.4-6 depicts typical operation and stowage during EVA.

To provide EVA access to the payload bay, a minimum clearance of 121.9 cm. (48 in.) is required between the aft hatch ($X_0$576 bulkhead) and the payload.

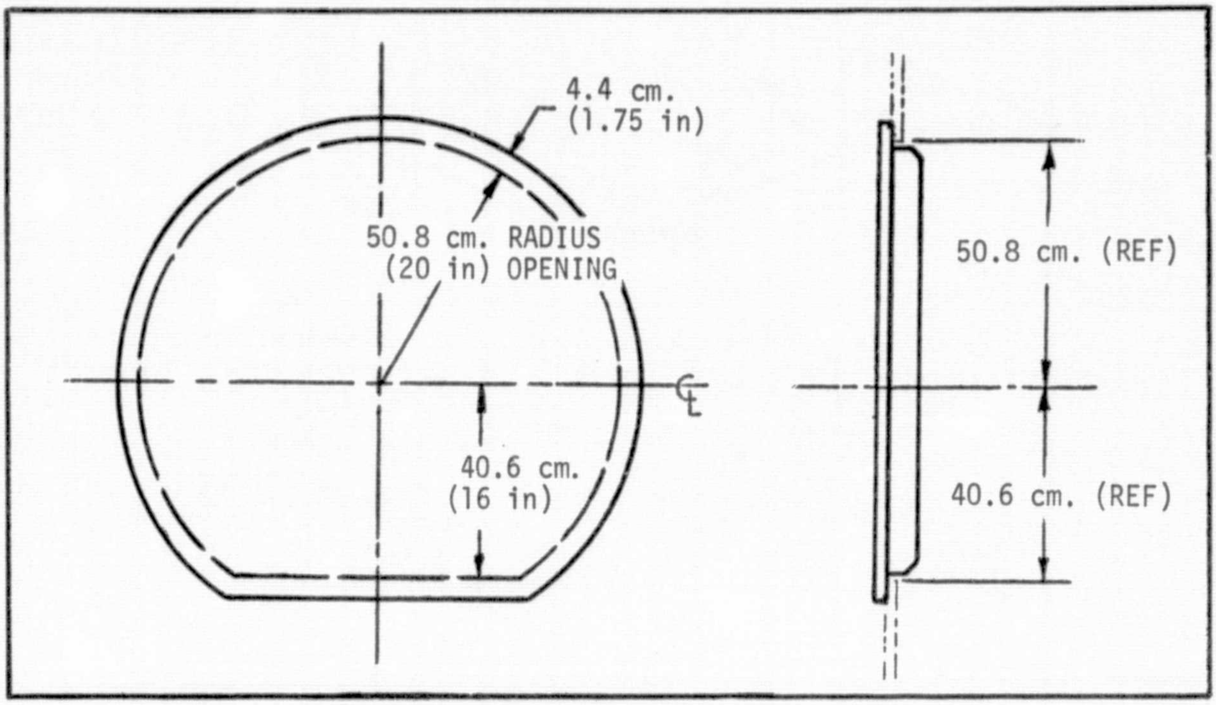


FIGURE 2.4-5: Typical Hatch Configuration

Each airlock hatch has the following characteristics:

- Designed for multiple open/closed cycles
- Capability of being locked/unlocked from either side
- An interlock prevents unlatching during the opening cycle prior to pressure equalization
- Actuating handle locks automatically when activated to the open and closed positions
- Hinges permit hatch to swing open until automatically locked into a stowage position
- Hatch operating mechanism relieves all residual differential pressure prior to unlatching
- Latch crank, locking mechanism, pressure equalization valve and Δ p gauge are located on the hatches
- Hatch windows are TBD.

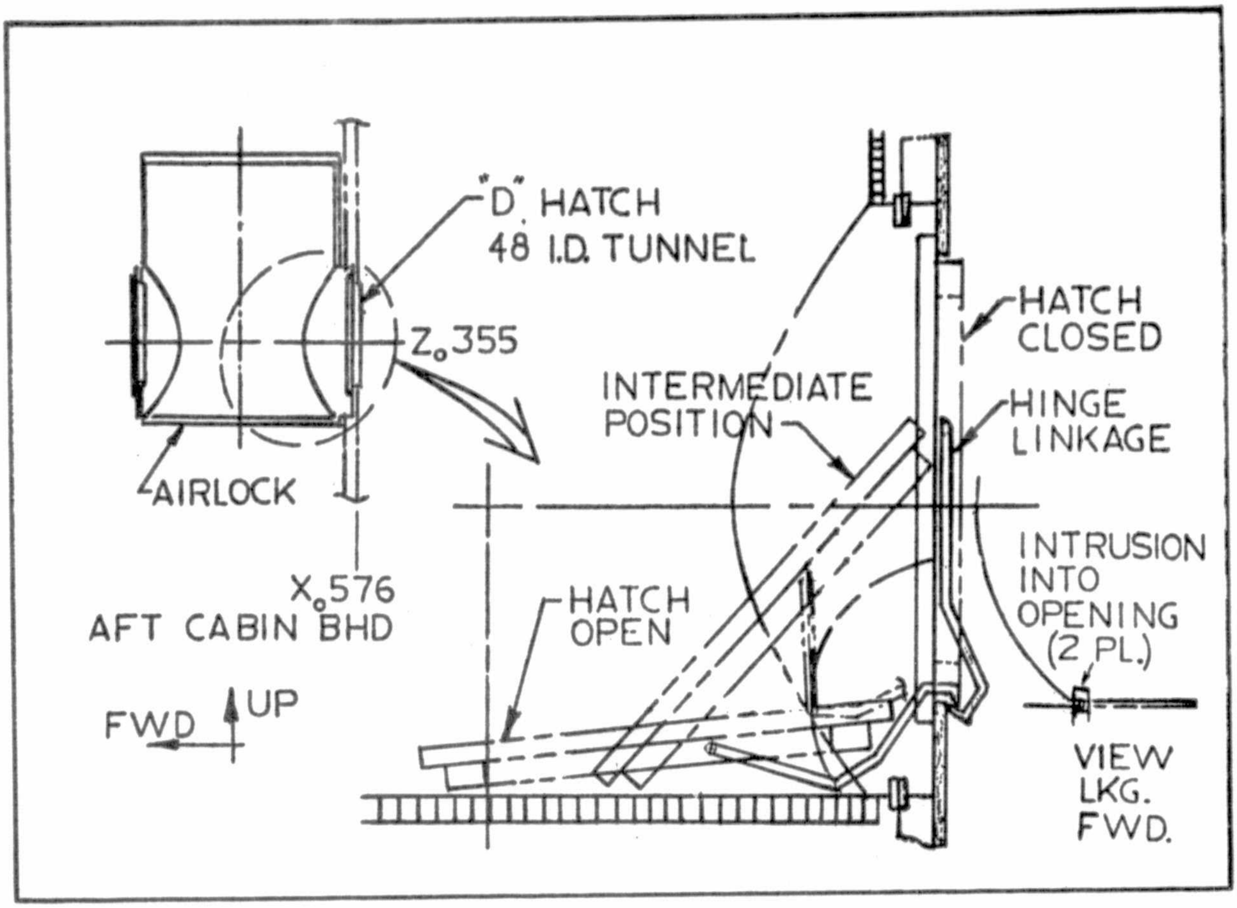


FIGURE 2.4-6: Airlock Aft Hatch

2.4.3 Airlock Support Subsystem

The airlock support subsystem is designed to operate on demand during on-orbit phases to provide support for EVA. The system provides the following:

- Oxygen supply
- Suit cooling potable water supply
- Power
- Audio communications

- Instrumentation
- EVA equipment stowage
- EMU donning/doffing station
- EMU recharge station
- Various valves, gauges and switches for control functions.

The overall airlock support subsystem is depicted schematically in Figure 2.4-7.

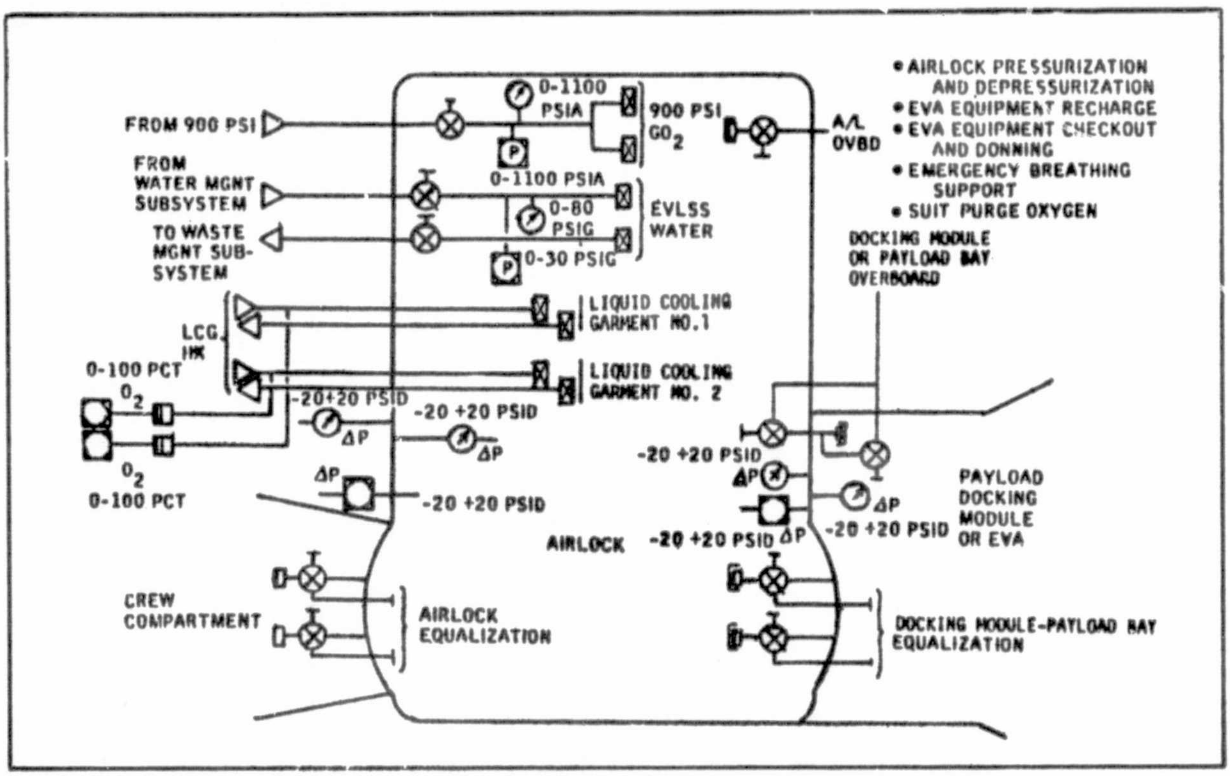


FIGURE 2.4-7: Airlock Support Subsystem

Because of the multiple location requirements of the airlock, the utility line interface is provided as shown in Figure 2.4-2 to permit either mid-deck or payload bay airlock installation.

Control and display panels located in the airlock control, monitor and

activate the various airlock support subsystems (Figure 2.4-8).

A variety of handholds, straps, and foot restraints are provided in the interior of the airlock for use in pre- and post-EVA operations. As illustrated in Figure 2.4-9, handholds are located adjacent to the control and display panels, around the periphery of the hatches, around the walls, and on the deck. An IVA foot restraint system is provided on the ceiling and the deck; an EVA foot restraint is provided on the ceiling.

2.4.3.1 Depressurization/Repressurization

2.4.3.1.1 Depressurization - Following completion of the pre-EVA operations (astronaut EMU donning and checkout, and hatch closure), EVA is initiated by opening the airlock depressurization valve to the first of three discharge positions, followed by the second and third positions over a specified period of time to maintain a depressurization rate of 70 $kg/m^2/sec$ (0.1 psi/sec) (Figure 2.4-10).

The depress valve is physically located in the airlock on the control and display panels (ref. Figure 2.4-8) and is protected by a valve cover and debris screen on the intake (airlock) side of the valve. Depressurization requires approximately five minutes, after which the crewmen may open the aft airlock hatch and proceed with EVA.

2.4.3.1.2 Repressurization - Following EVA, when the crewmen have returned to the airlock and closed the aft hatch, repressurization is initiated through use of redundant repressurization valves, operable from either the airlock or the Orbiter mid-deck. Each valve has two positions and is protected by a debris screen on the intake side (mid-deck) and an air diffuser on the exit (airlock) side. The normal repressurization mode requires one valve to be opened to the "normal" position. Figure 2.4-11 presents a normal repress profile.

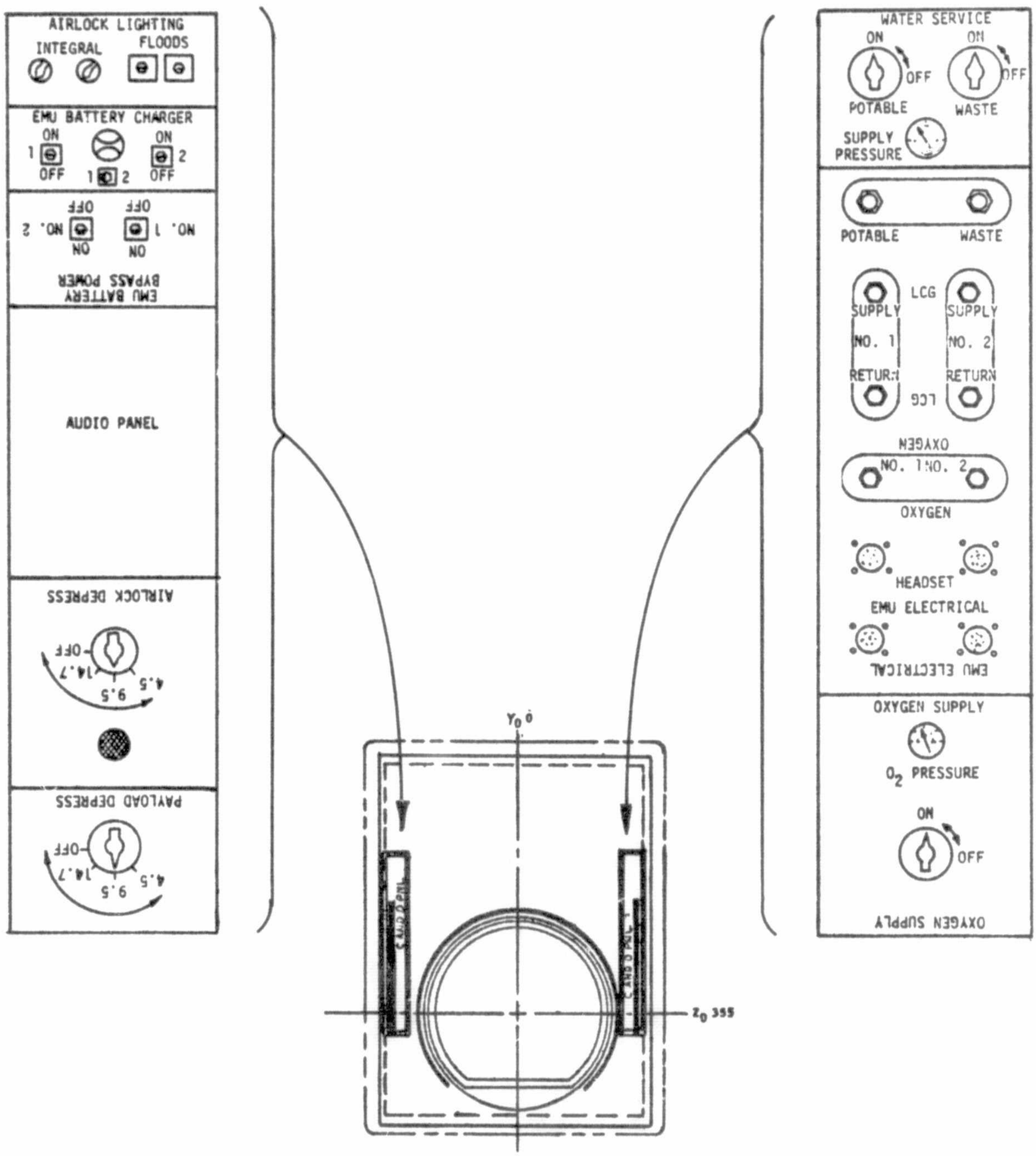


FIGURE 2.4-8: Airlock Control Panels

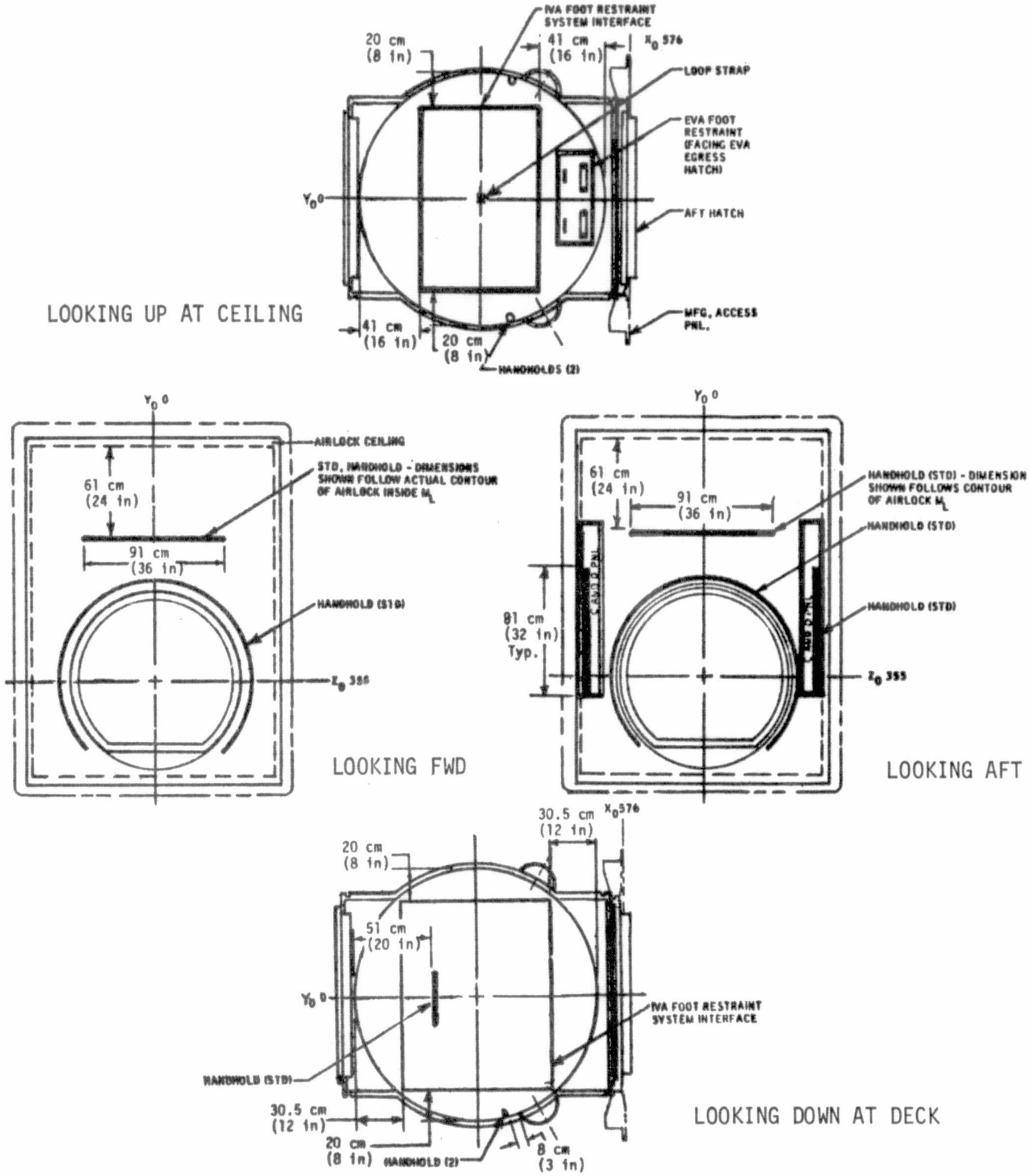


FIGURE 2.4-9: Airlock Handholds and Foot Restraints

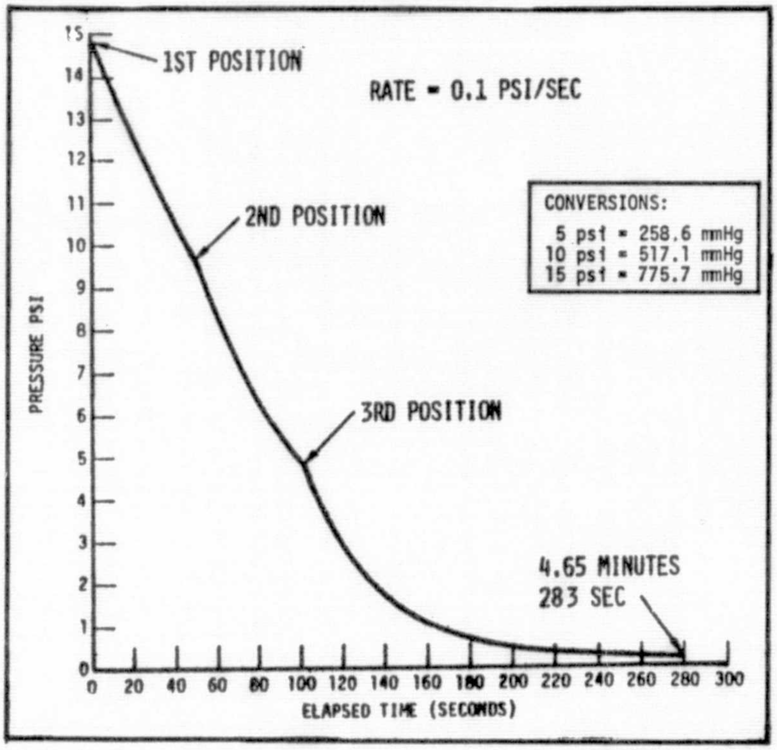


FIGURE 2.4-10: Airlock Depressurization Profile

Three emergency airlock repressurization modes are available using a combination of normal and emergency repressurization valves. The emergency repress profiles are shown in Figure 2.4-12, which specifies the valve position, rate, cabin pressure and time.

2.4.3.2 Prebreathing, EMU Purge, EMU Recharge and Emergency Breathing Oxygen Supply

The airlock provides redundant quick disconnect fittings to supply 56.3 kg/cm^2 (900 psia) oxygen for crewman prebreathing, purging and recharging the EMU and recharging the Portable Oxygen Systems (POS) for emergency breathing (ref. Subsection 2.2.4.1).

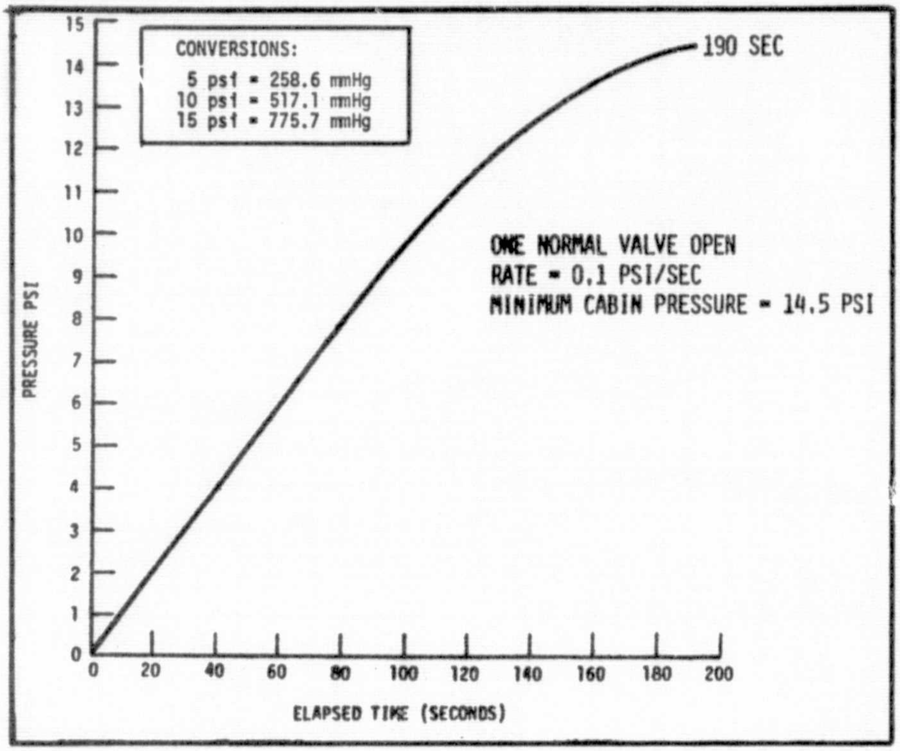
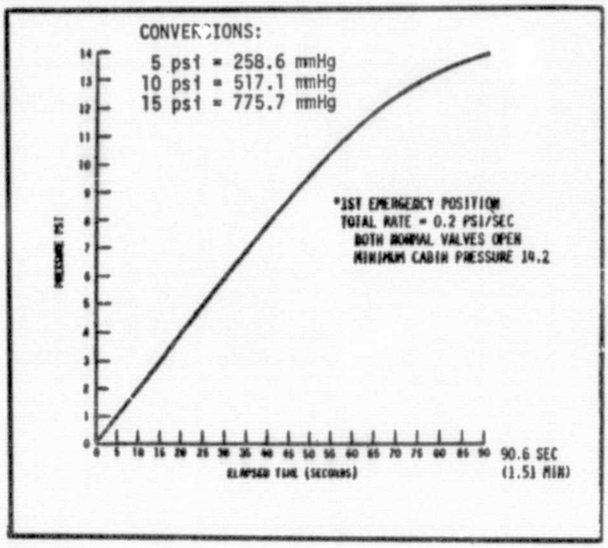


FIGURE 2.4-11: Airlock Repressurization Profile--Normal Mode

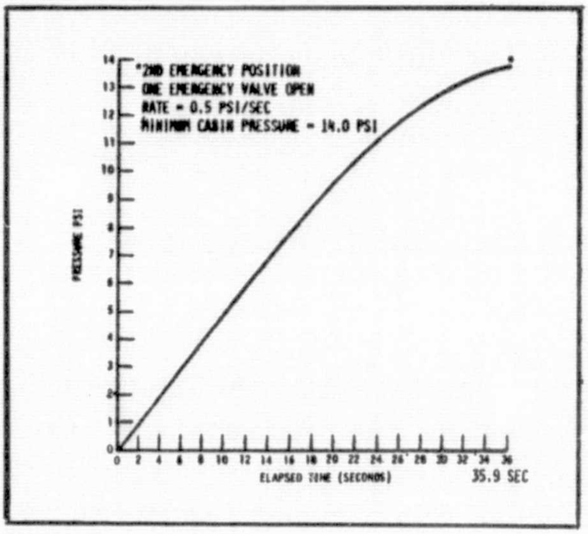
2.4.3.2.1 Prebreathing - The POS, supplied as equipment with multiple use capability, will also be used during EVA preparation for prebreathing. The POS connects directly to the airlock oxygen supply fittings.

2.4.3.2.2 EMU Purge - Pre-EVA purging of the EMU is accomplished by connecting the EMU to the airlock O_2 supply. Oxygen required for each EMU purge is 0.38 kg. (0.83 lb.) and is payload chargeable if more than two EVA missions are conducted per Shuttle flight.

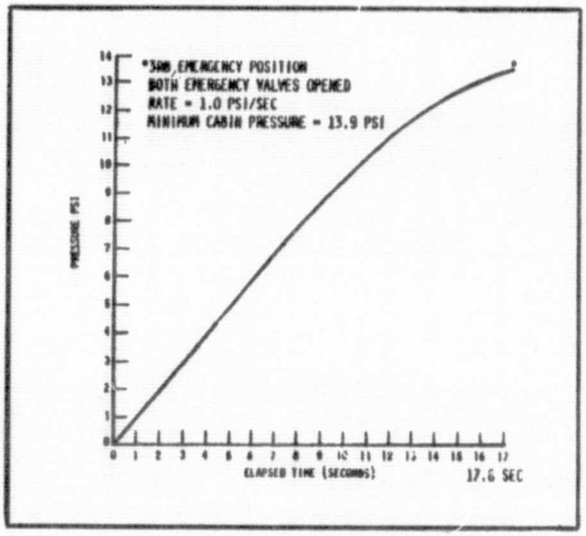
2.4.3.2.3 EMU Recharge - Upon completion of EVA, each EMU is recharged in preparation for future EVA's. The doffed EMU is connected to the airlock O_2 supply and refilled, requiring 0.73 kg. (1.6 lbs.) of oxygen per refill.



First Emergency Mode



Second Emergency Mode



Third Emergency Mode

FIGURE 2.4-12: Airlock Emergency Repressurization Profiles

All EMU O_2 recharges exceeding two are weight-chargeable to the payload.

2.4.3.2.4 Emergency Breathing - Emergency breathing capability is provided by the POS which contains a 10-minute emergency O_2 supply. The POS can be recharged by connecting to the airlock O_2 system.

2.4.3.3 Potable/Waste Water

During the post-EVA period the EMU cooling water system is recharged by connecting the airlock water supply to the EMU fill connection, and the EMU waste water fitting to the airlock waste management system. Approximately 0.9 kg. (2 lbs.) of condensate water collected during EVA is dumped to the Orbiter waste management system. The EMU water system is then recharged, requiring 4.1 kg. (9.0 lbs.) of water from the Orbiter drinking water management subsystem. Recharge water is also payload chargeable in excess of two refills.

2.4.3.4 EMU Contaminant Control

The EMU requires replacement of the Contaminant Control Cartridge (CCC) following each EVA. Spare cartridges are stowed in the airlock and are installed in the EMU as part of the EMU recharge procedure (payload chargeable in excess of two per Shuttle mission).

2.4.3.5 EMU Battery

The EMU batteries require recharging following each EVA. The recharge is accomplished by connecting the EMU battery to the airlock EMU electrical connector. Battery recharge time is 12-16 hours.

2.4.3.6 Liquid Cooling Garment (LCG) Heat Exchanger

During the pre- and post-EVA periods, cooling is supplied to the crewmen by connecting the EMU liquid cooling loop to the airlock LCG fittings. The EMU pump circulates the LCG water through the Orbiter LCG heat exchanger rejecting up to 140 gm-cal/sec (2000 BTU/hr) per crewman.

2.4.3.7 EMU Donning/Doffing and Checkout Station

The EMU donning and checkout station will be located in the airlock. Donning aids such as handholds and foot restraints (ref. Figure 2.4-9) are provided to permit each crewman to don the EMU unassisted. The donning station will also permit the crewman to perform the doffing operation unassisted. Two donning or two doffing operations can occur simultaneously.

2.4.3.8 EMU Stowage

Provisions will be made for stowing the EMU's in the airlock to facilitate donning/doffing and system recharge. Figure 2.4-13 illustrates an EMU stowage concept.

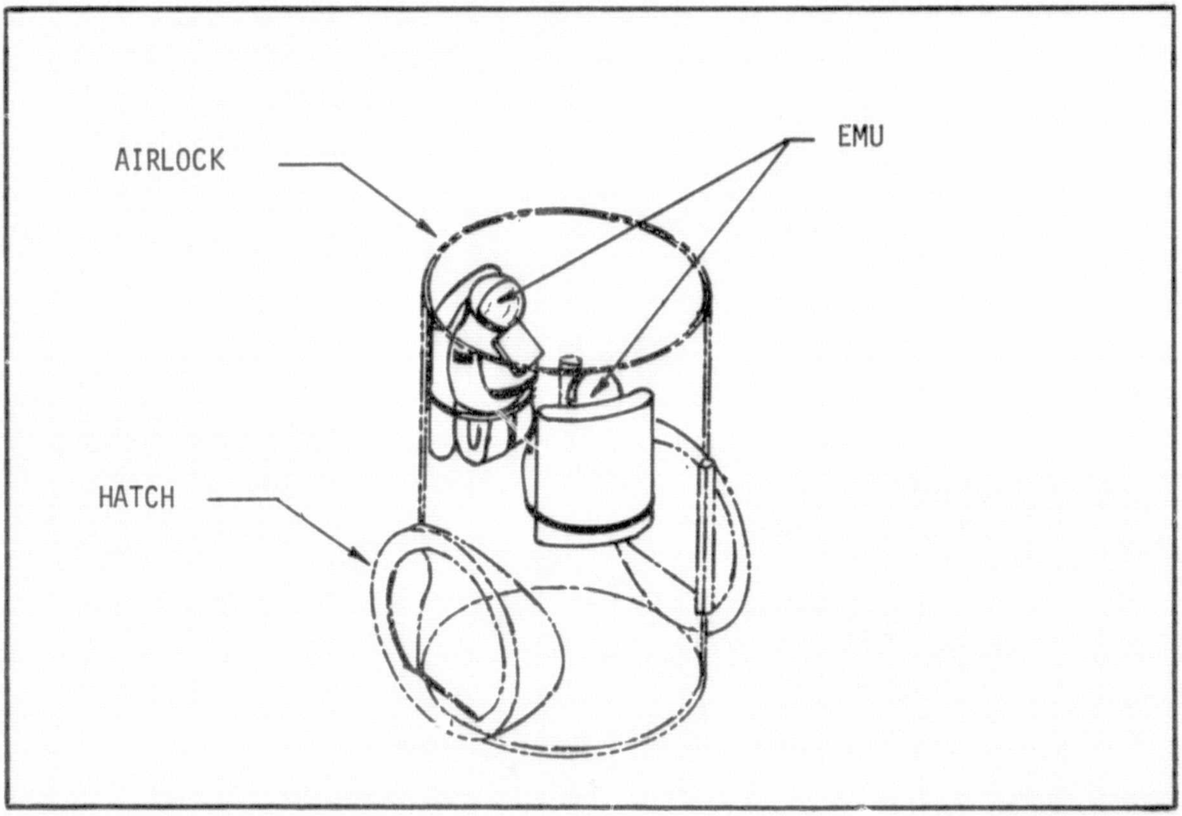


FIGURE 2.4-13: EMU Stowage in Airlock

2.5 AIRLOCK (EXTERIOR), TUNNEL ADAPTER, AND DOCKING MODULE

2.5.1 Introduction

In addition to the interior (mid-deck) installation, the airlock is capable of being installed in two alternate locations depending upon mission requirements. One is to reverse the unit from the internal installation and attach it to the aft ($X_0$576) bulkhead in the payload bay. The other locates the airlock on the tunnel adapter in the payload bay. In each case, the same basic airlock is used; only the installation is different. The airlock support subsystems described in Section 2.4 are also available in the external and tunnel adapter airlock configurations. A third alternative for EVA operations is also available as a docking module located on the tunnel adapter in lieu of the airlock. This section will be limited to a discussion of the two alternate airlock installations and the docking module installation.

2.5.2 Basic Description

2.5.2.1 External Airlock

The external airlock is essentially the same as the internal airlock with the exception of: (1) being moved aft into the payload bay, and (2) requiring the application of insulation to the airlock exterior for protection from the temperature extremes of the space-exposed payload bay. Figure 2.5-1 depicts the external airlock installation in the Orbiter payload bay. The external airlock attaches to the aft ($X_0$576) bulkhead via the access panel in the same manner as the internal airlock (ref. Figure 2.4-3). A minimum of 2.74 m. (9 ft.) of free space is required between the Orbiter aft bulkhead and the forward portion of the payload to permit airlock installation and a free EVA path from airlock aft hatch to the payload bay.

2.5.2.2 Airlock/Tunnel Adapter

For certain missions, to provide both an EVA capability and a shirtsleeve atmosphere between the Orbiter mid-deck and the manned payload (Spacelab) is desirable. To satisfy this requirement, a tunnel adapter will be installed

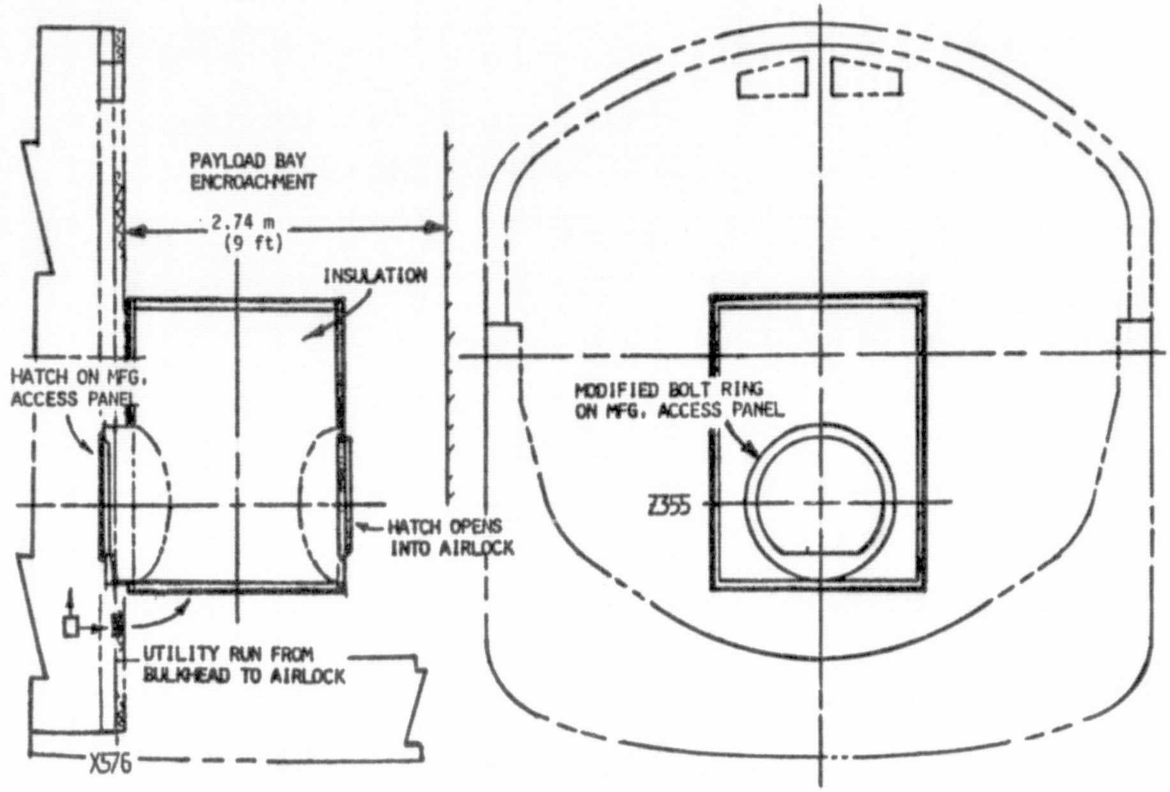


FIGURE 2.5-1: External Airlock Installation

in lieu of the external airlock and attached to the manufacturing access panel on the $X_0$576 bulkhead. The tunnel adapter has two access hatches: one on top for access to an airlock and the other on the aft end for access to the payload. For EVA, an airlock will be placed on top of the tunnel adapter and stabilized through a structural connection to the $X_0$576 bulkhead, Figure 2.5-2. The airlock and tunnel adapter require external insulation for protection from the temperature extremes in the payload bay. The tunnel adapter adds TBD kg., weight-chargeable to the payload.

2.5.2.3 Docking Module

For missions requiring direct docking of two vehicles, a docking module can

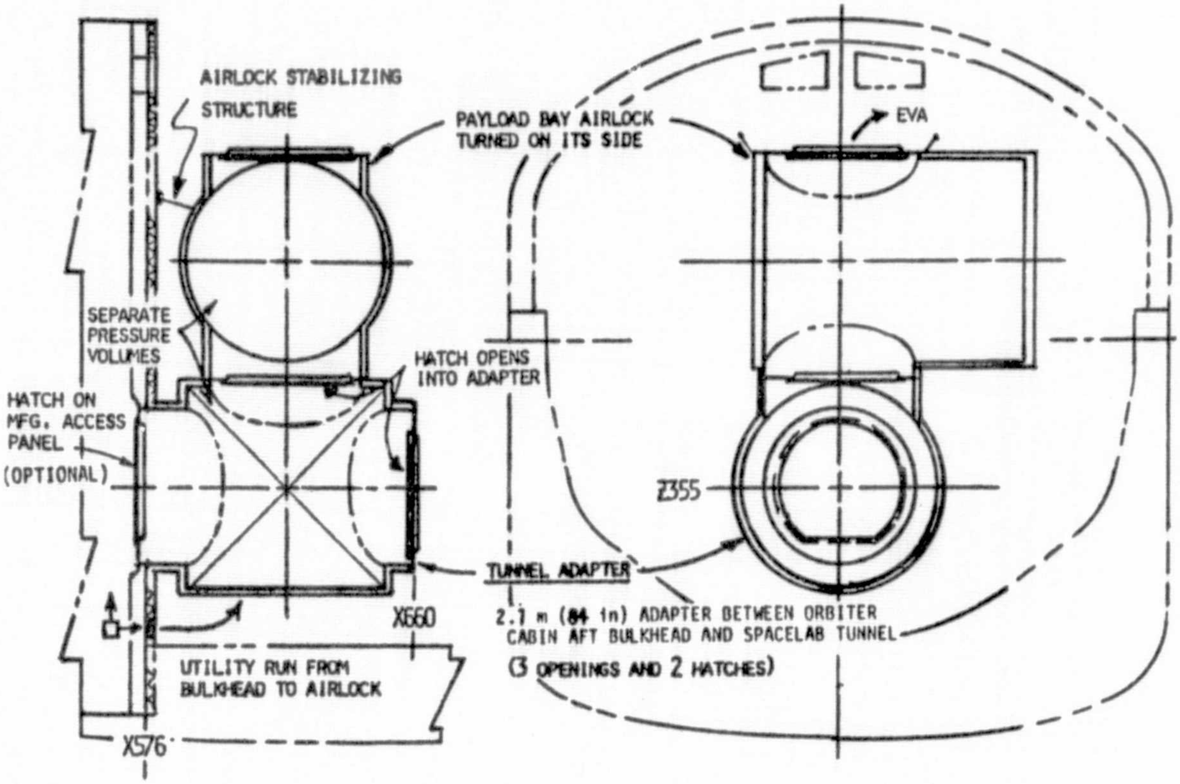


FIGURE 2.5-2: Tunnel Adapter/Airlock Installation

be substituted for the airlock and installed on the tunnel adapter. The docking module is extendible and provides an airlock function for EVA--for two crewmen when extended or for one crewman when retracted. The docking module adds 1574 kg. (3470 lbs.), weight-chargeable to the payload. Docking module design and support subsystem details are TBD, Figure 2.5-3.

2.5.3 Airlock Support Subsystems

The airlock support subsystems identified for the internal airlock (Section 2.4.3) apply to the external airlock, except for relocation of the EVA foot restraint on the airlock ceiling and the handhold on the airlock deck as shown in Figure 2.5-4.

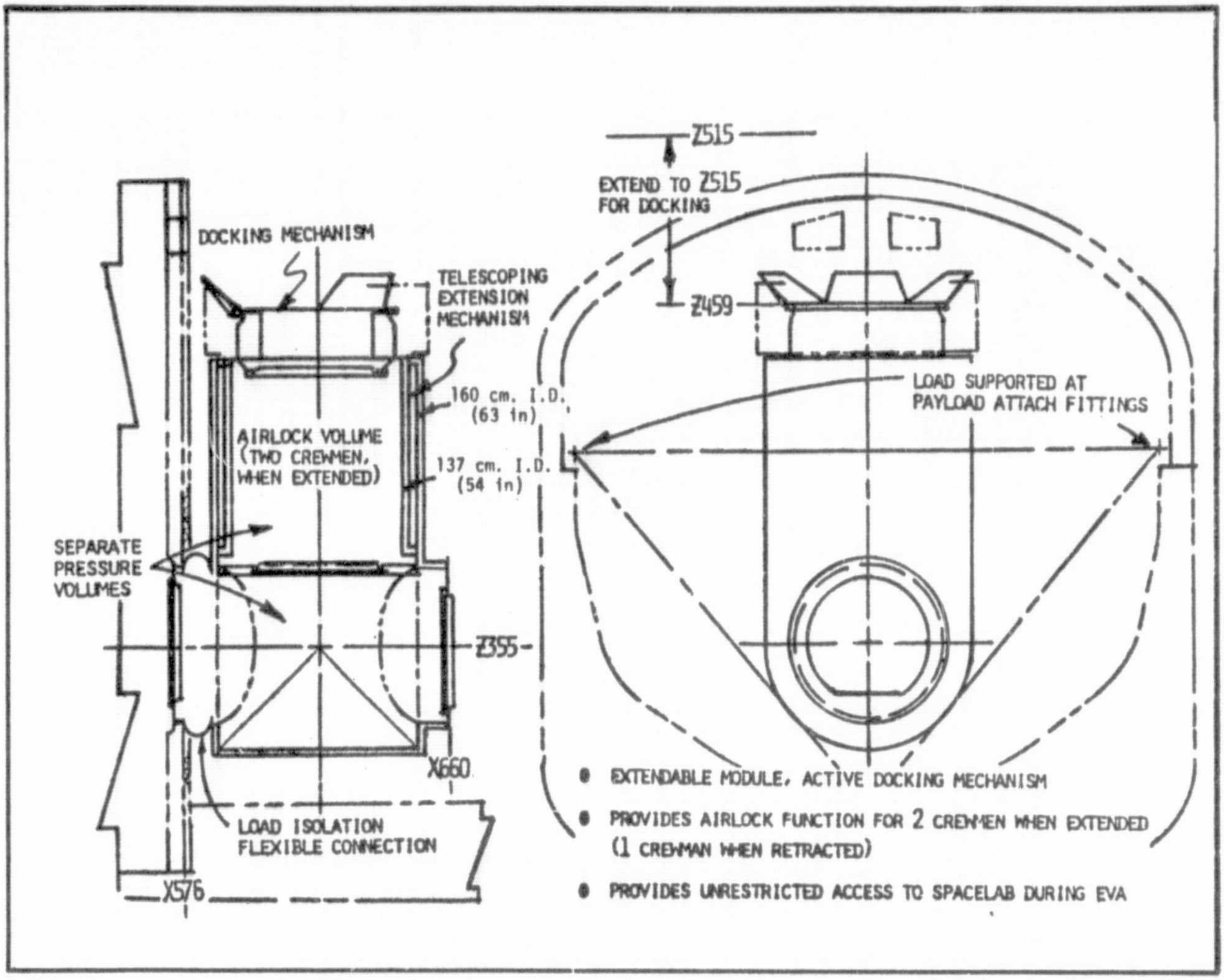
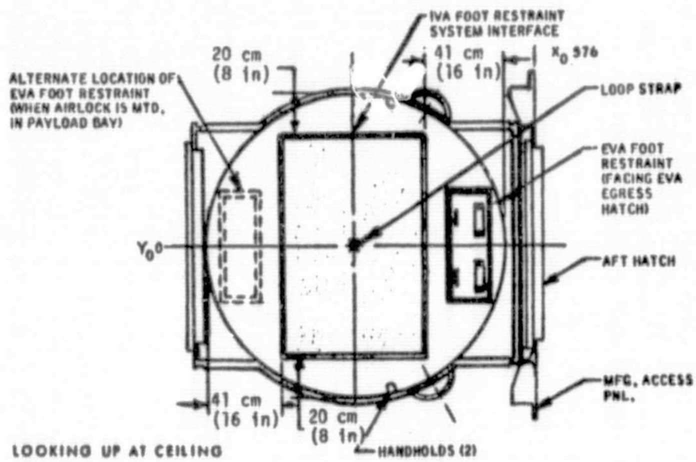


FIGURE 2.5-3: Docking Module Installation



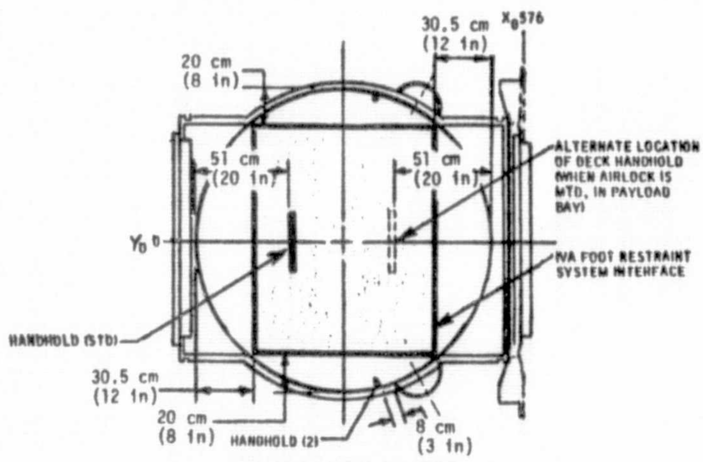


FIGURE 2.5-4: Alternate Foot Restraint and Handholds for External Airlock

2.6 EVA TRANSLATION AIDS

2.6.1 Introduction

On previous U. S. space programs, handrails and handholds have been the prime support systems in assisting crew transfer and stabilization during orbital "zero-gravity" extravehicular missions. The units have proven to be a fully satisfactory, reliable, and economical method for crew translation and manual equipment transfer (e.g., limited size and mass). The handrails and handholds are applicable both inside the pressurized vehicle and on exterior surfaces. The units provide convenient locations for temporary restraint/attachment of equipment and also provide local protection to vehicle surfaces and components from possible damage by the EMU suited crewman. Single handrails are normally sufficient for most crew translation applications, while dual handrails are convenient when precise body orientation is required or where contact with the vehicle must be avoided.

2.6.2 Shuttle EVA Translation Requirements

Based on the overall Shuttle vehicle, Orbiter subsystems, and payload design/servicing philosophy, the EVA crewmen may be required to access all areas of the payload bay, berthed payloads, selected locations on the Orbiter exterior and free-flying satellites. The access requirements could be either planned or contingency. To access the above areas, EVA equipment is being developed by the Space Shuttle Program and is available for use by the payload community. Cost to the payloads (i.e., weight, volume, and consumables only) will be assessed on an individual flight and payload requirement basis. However, the Shuttle Orbiter will provide a baseline EVA translation system inside the payload bay on each Shuttle flight at no cost to the payload.

EV crew translation support systems being developed, tested, and flight qualified for the Space Transportation System (STS) include handholds, handrails, remote manipulator system (RMS), and manned maneuvering units (MMU's). The primary purpose of the remote manipulator system is to deploy and retrieve payloads, but the RMS will be equipped with handrails to aid

EV crew translation and provide crew rescue support from a disabled Orbiter. The manned maneuvering units will be employed by the Orbiter primarily for contingency EVA activities such as vehicle exterior inspection, maintenance or repair, and on-orbit crew rescue when the disabled Orbiter is unstable.

When the payloads use the Shuttle EVA capability to accomplish specific payload tasks, payload design must accommodate the necessary translation interface requirements and EVA translation equipment if not included in the Shuttle baseline system. Ancillary EVA translation provisions may be added to the Orbiter as payload weight chargeable items.

2.6.3 Shuttle EVA Translation Aids

Orbiter requirements for baseline EVA translation aids are presently being identified by the NASA and NASA contractors. System design concepts are in the initial phase, and potential requirements/applications are under continuing study and evaluation. Therefore, definition of design details and handrail locations is limited and subject to change. The material presented represents the development status in early 1976.

2.6.3.1 Payload Bay Mobility Aids--Baseline System

The Orbiter baseline EVA translation system for accessing areas of the payload bay consists of handrails and handholds located in the following areas (Ref. 2.6.1):

- Airlock exterior when the airlock is located outside the Orbiter crew cabin
- Orbiter forward bulkhead at station $X_o 576$
- Payload bay door hinge lines on both the port and starboard sides
- Orbiter aft bulkhead at station $X_o 1307$.

Crew mobility aids will be provided in the above areas by the Orbiter on each Shuttle flight--no cost will be assessed to the payloads.

2.6.3.1.1 Airlock External Mobility Aids

Handrails are located on the exterior of the airlock when the airlock is installed in the payload bay. The handrails provide mobility aids for airlock ingress/egress and access to additional handrails on the forward bulkhead and/or tunnel adapter. The airlock can be installed in the payload bay with or without a tunnel adapter module. The tunnel adapter allows shirtsleeve access to a pressurized Spacelab while performing extravehicular activities. Airlock handrail locations (tentative) are depicted in Figures 2.6-1 and 2.6-2.

2.6.3.1.2 Forward Bulkhead Handrails (Sta. X_o576)

Handrails located on the Orbiter forward bulkhead (sta. X_o576) provide a crew translation route to access (1) the mobility aids traversing the payload bay, (2) equipment mounted on the forward bulkhead, and (3) the lower portion of the payload bay (direct route). Forward bulkhead handrail locations (tentative) are shown in Figure 2.6-3.

2.6.3.1.3 Payload Bay Door Handrails

EVA handrails extend the length of the Orbiter payload bay on both the port and starboard sides. The handrails are segmented to provide clearance for radiator and door actuating mechanisms, RMS and radiator fittings, and radiator freon lines. The handrails provide a translation route through the payload bay to the aft bulkhead (or payloads) with the payload bay doors in the closed position. When the payload bay doors are open, a translation route is provided outside the maximum payload envelope to access berthed or attached payloads and the Orbiter aft bulkhead. Payload bay door EVA handrail locations are shown in Figure 2.6-4. Handrails in addition to those baselined (e.g., provided by the Orbiter vehicle) may be required to access pallet experiments/payloads. All additional EVA mobility aids are payload chargeable.

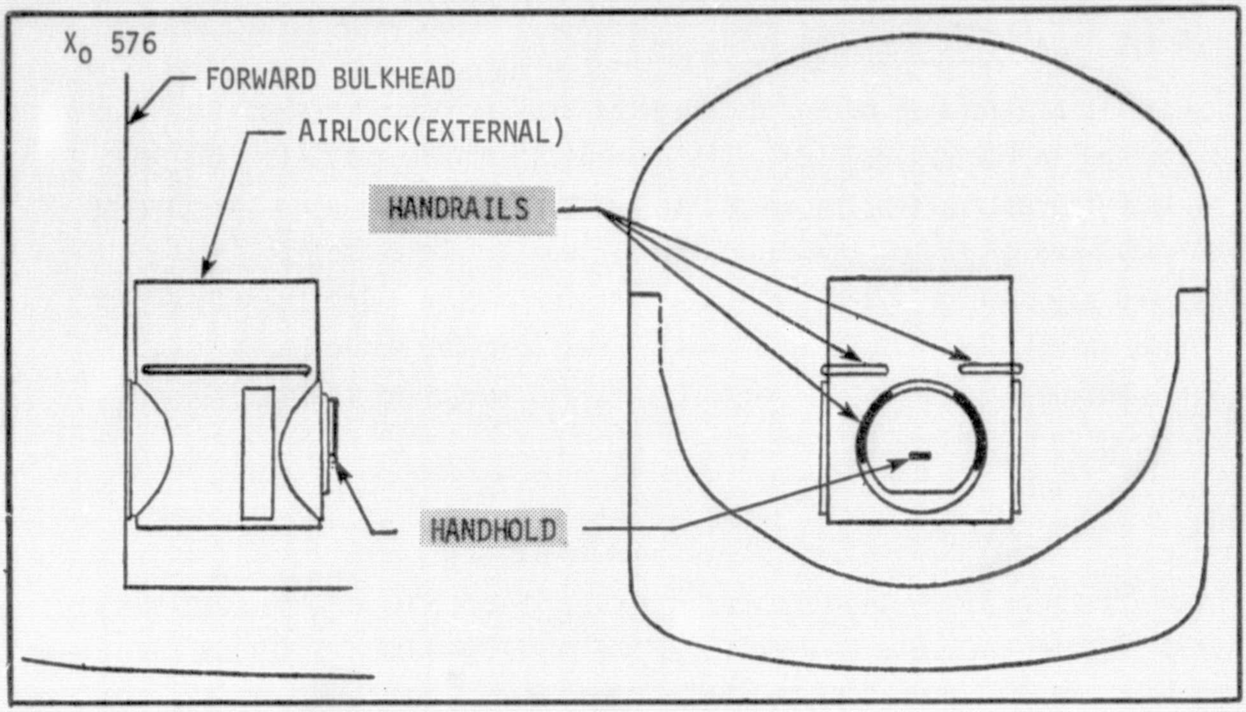


FIGURE 2.6-1: EVA Handrails on External Airlock (Concept)

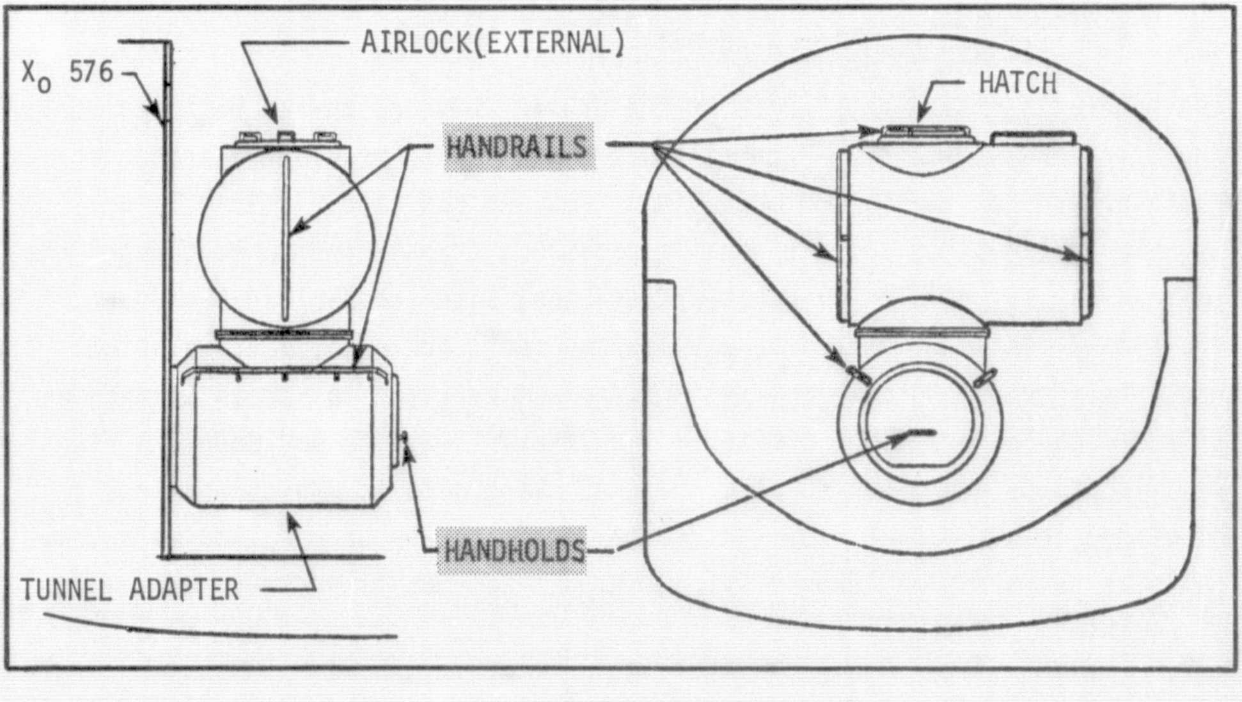


FIGURE 2.6-2: EVA Handrails on External Airlock and Tunnel Adapter (Concept)

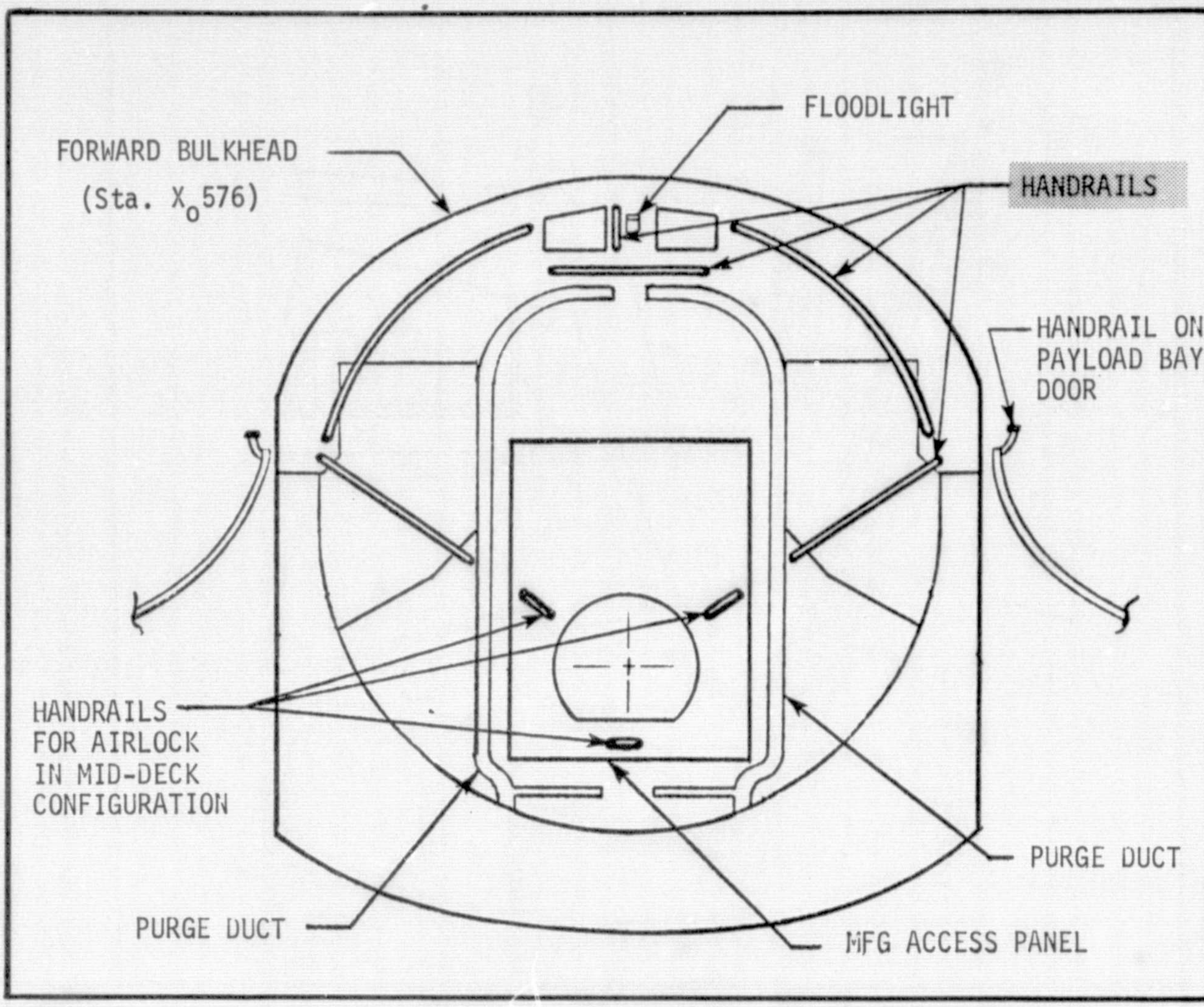


FIGURE 2.6-3: Forward Bulkhead Handrail Location (Concept)

2.6.3.1.4 Aft Bulkhead Handrails (Sta. X_o1307)

The EVA handrails located on the Orbiter aft bulkhead provide access to bulkhead mounted equipment, passive door latching mechanisms, active door latching mechanisms (i.e., when the doors are in the closed or near-closed positions), and a direct route to the lower portion of the payload bay. Conceptual locations of the aft bulkhead handrails are depicted in Figure 2.6-5. The handrails are removable to accommodate Orbiter maneuvering system (OMS) kits or to avoid interference with payloads or supporting equipment.

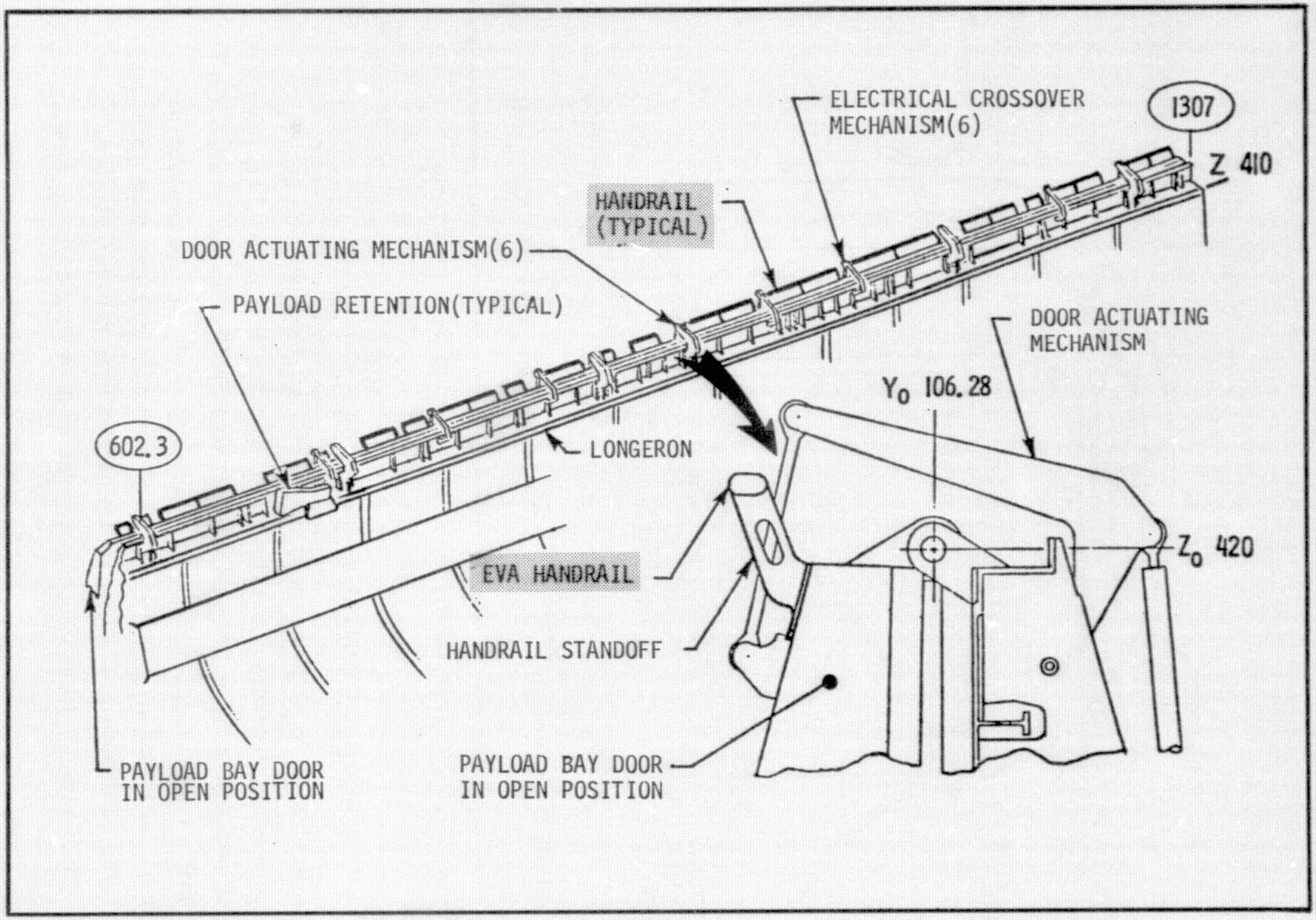


FIGURE 2.6-4: Shuttle Payload Bay Door Handrail Location (Concept)

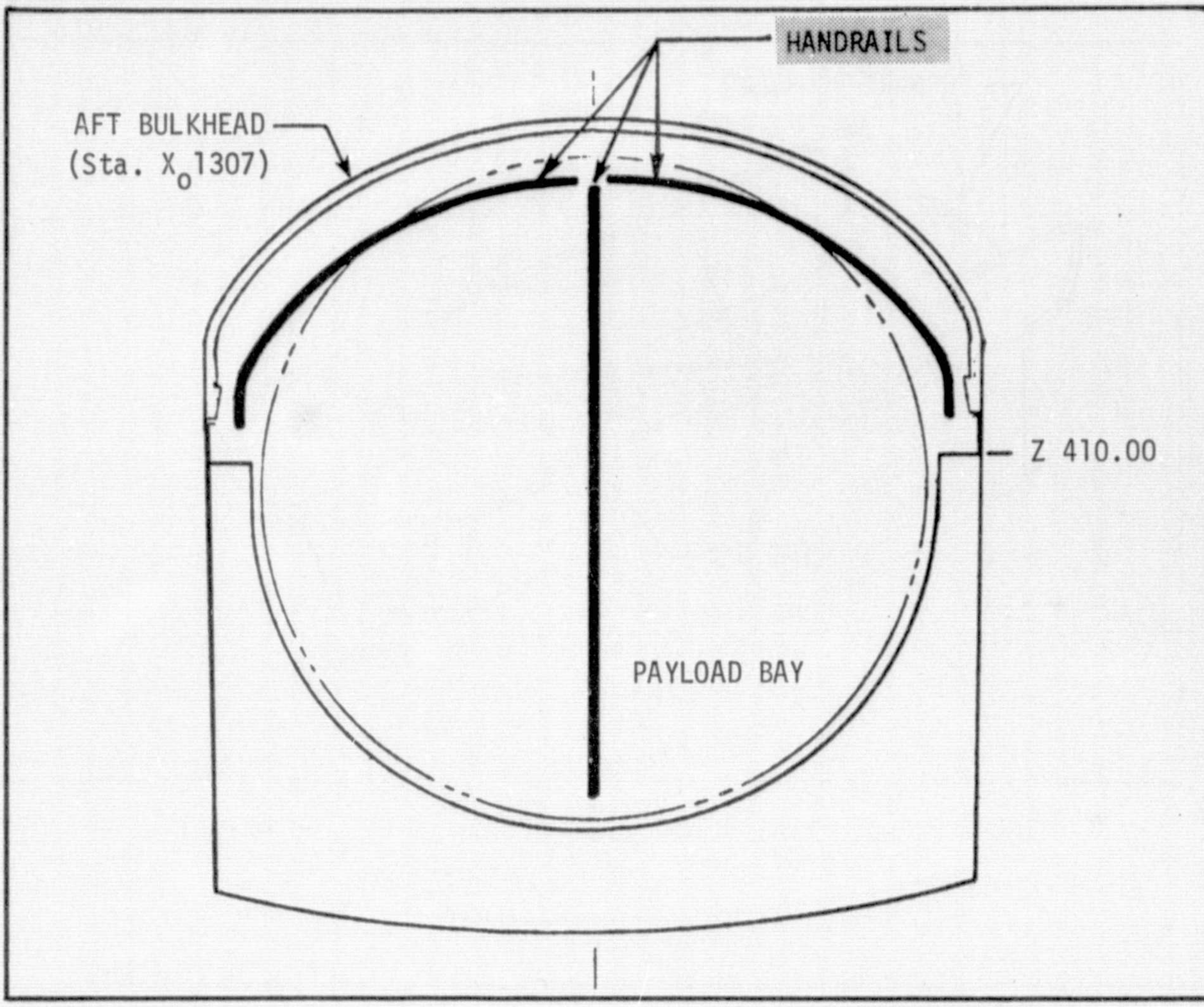


FIGURE 2.6-5: Aft Bulkhead Handrail Location (Concept)

2.6.3.2 RMS EVA Mobility Aids

The Shuttle Remote Manipulator System (RMS) is designed to accommodate EVA handrails along the full length of the manipulator arm. The arm can provide the EV crewman an access route to berthed payloads and to limited external areas of the Orbiter (Figure 2.6-6). The RMS manipulator arm is also being considered as a crewman restraint and stabilization aid for EVA worksite functions. In the crewman restraint capacity, the RMS would utilize a portable EVA workstation as the end effector and position the workstation for crewman ingress (Figure 2.6-7). However, the following

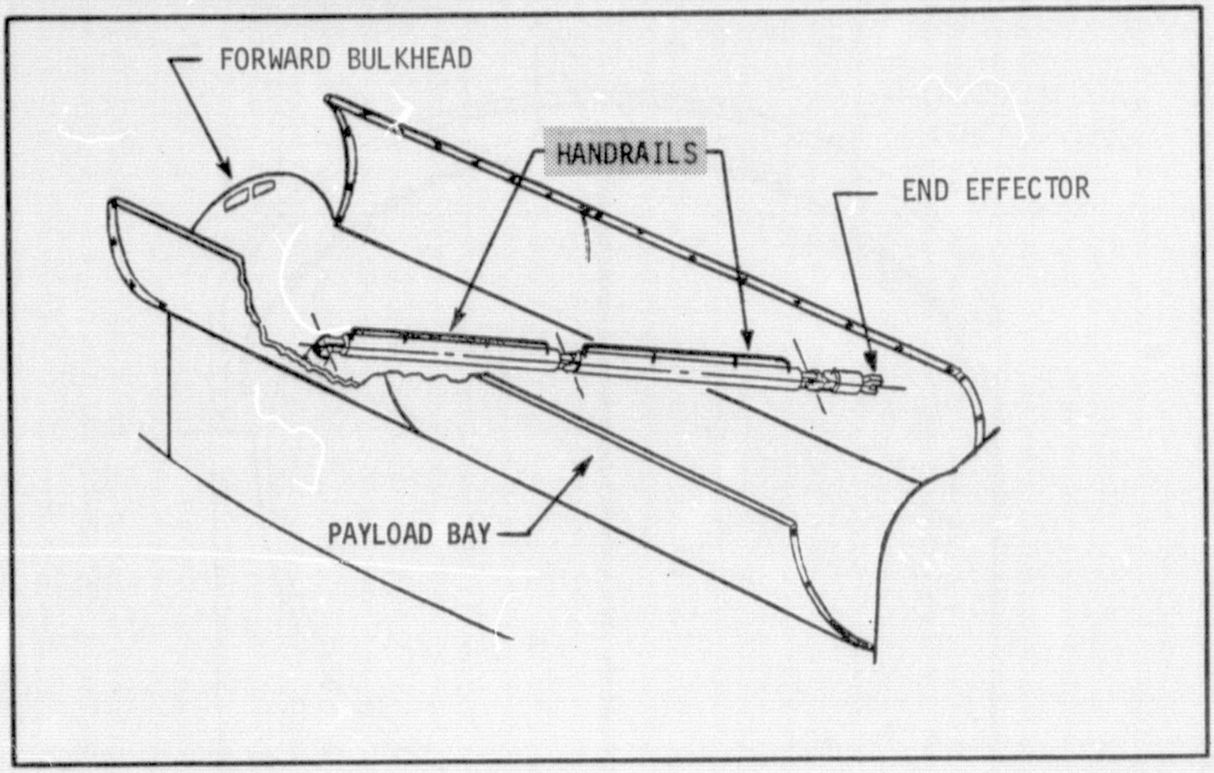


FIGURE 2.6-6: Manipulator Arm EVA Handrails (Tentative)

NASA developed criteria must be acknowledged prior to utilizing the RMS in support of EVA (Ref. 2.6.2):

- A fixed manipulator arm (end effector secured at the end point of translation, worksite, workstation or work platform) may be used to provide a translation path.
- Operation of the manipulator in a "cherry picker" mode will be considered when sufficient data are available.

An overview of the Shuttle RMS configuration and operational characteristics is provided in Section 2.3 of this report.

2.6.3.3 MMU Translation

Manned Maneuvering Units (MMU's) will be available for the Shuttle

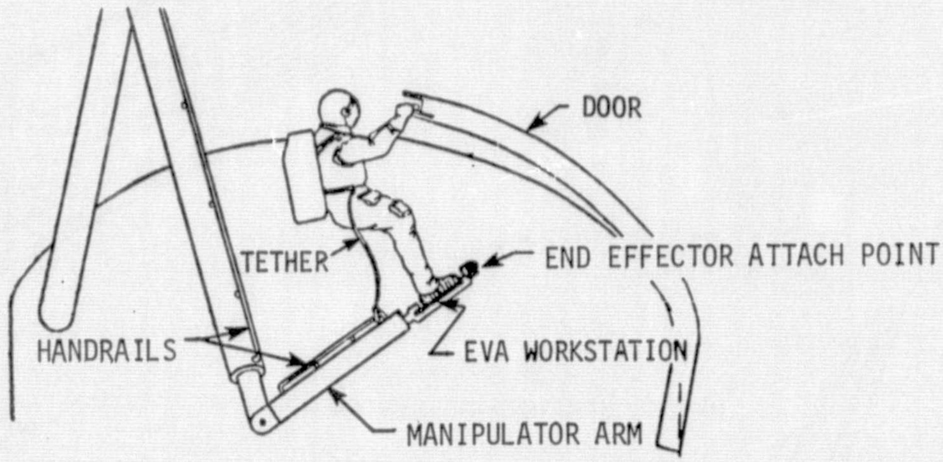


FIGURE 2.6-7: RMS Mounted Portable EVA Workstation (Concept)

operational flights to support free-flying payload EVA operations in the immediate vicinity of the Orbiter (Figure 2.6-8). The MMU's will also be available to support orbital flight tests of the Shuttle Orbiter as a fly-around inspection and possible inflight repair capability. The MMU's will be stowed in the payload bay on or near the Orbiter forward bulkhead and are rechargeable on-orbit. The units can be donned, doffed, and serviced by one crewman. The MMU range is currently specified as 100 m. (330 ft.) from the Orbiter with a minimum delta velocity (ΔV) of 20.1 m/sec (66 ft/sec) per charge. Additional MMU capabilities data and operational characteristics are provided in Section 2.8. Weight and volume only for the MMU's flown in support of payload functions are charged to the payload.

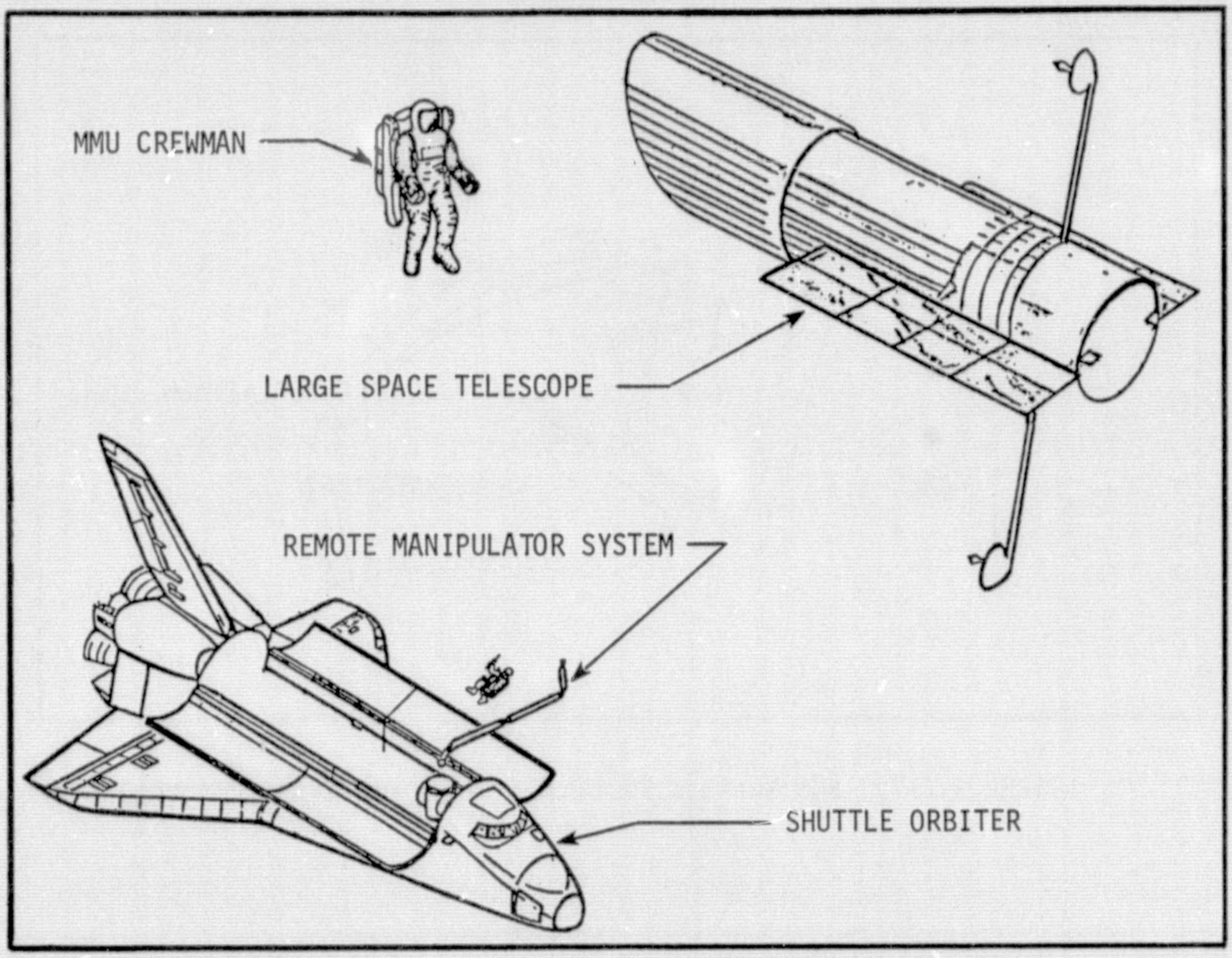


FIGURE 2.6-8: MMU Approaching Free-Flying Satellite

2.6.4 <u>Standard Handrail and Handhold Description</u>

The same general handhold and handrail configuration used in previous U. S. space programs is baselined for Shuttle application. The EVA handgrip dimensions, as depicted in Figure 2.6-9, were predicated on an optimum grip configuration with the EVA glove. The major cross-sectional axis is 3.35 cm. (1.32 in.), the minor axis 1.90 cm. (.75 in.). The minimum longitudinal grip length for EVA handholds is specified as 14.75 cm. (5.81 in.) to accommodate the EVA gloves. Standard handhold and handrail configurations are shown in Figure 2.6-10. The minimum standoff distance from the mounting

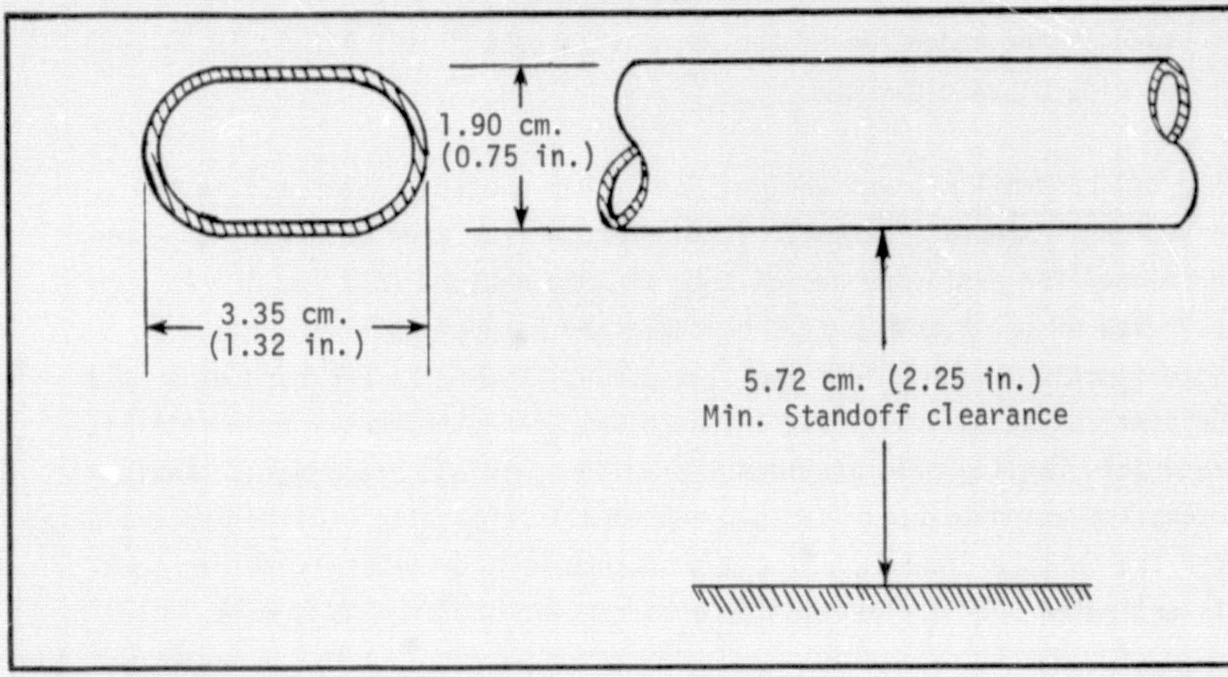


FIGURE 2.6-9: EVA Handrail Grip (Cross-section) Dimensions

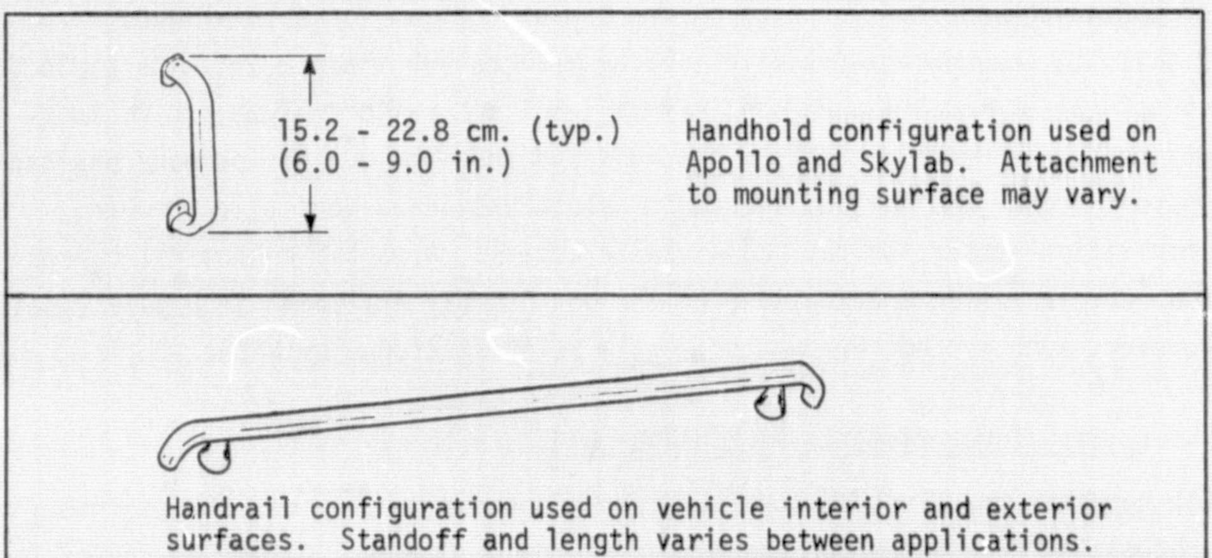


FIGURE 2.6-10: Standard EVA Handrail Configuration

surface to the underside of the handrail/handhold is 5.72 cm. (2.25 in.) to provide glove clearance.

The EVA handrail minimum design load is 830 newtons (187 lbs.) in any direction. Handrail/handhold standoffs used for crew tethering must be developed for a minimum design load of 2550 newtons (573 lbs.). An overview of the Space Shuttle handhold and handrail general design specifications is provided in Table 2.6.1. Handrails and handholds used on previous U. S. space programs were fabricated primarily from metallic materials ranging from aluminum tubing to stainless steel bars. Kevlar-epoxy and graphite-epoxy laminated handrails are being studied and evaluated for the Shuttle Program. A weight savings of approximately 30 per cent is estimated over the previously used tubular aluminum handrails.

2.6.5 Portable Handhold/Handrail Concepts

Although not baselined as Shuttle support systems, portable handholds and handrails for real-time, on-orbit installation by the EV crewman may be applicable in many payload servicing operations. Modification/development of portable handholds (as used in the Skylab Orbital Workshop--Figure 2.6-11) to incorporate positive locking devices for interfacing with payload structural elements may be cost effective (i.e., weight/volume) to various payloads. Extendible portable handrails to span the Orbiter primary payload support frames and payload structures could provide a versatile crewman translation system for payload worksite access. A portable handrail concept and representative application for the payload bay are shown in Figure 2.6-12. However, such systems are not presently being developed by NASA.

2.6.6 Structural Elements As Mobility Aids

The handrail and handhold configurations depicted in previous subsections are considered optimum for use by EVA crewmen. However, in the design of payload systems, many structural elements may be designed to provide mobility aids for the EVA crewman while still accommodating the primary function or objective.

TABLE 2.6.1: Handhold and Handrail General Design Characteristics

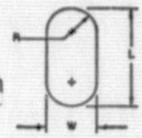
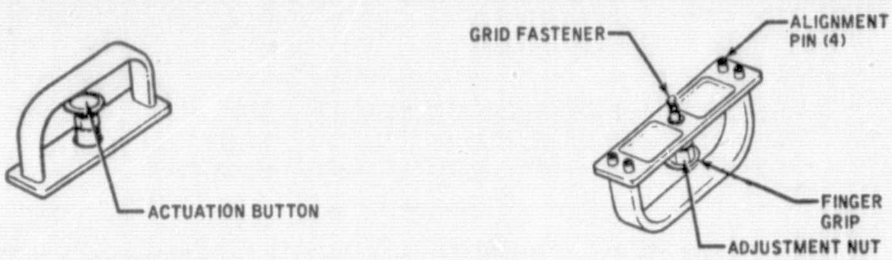
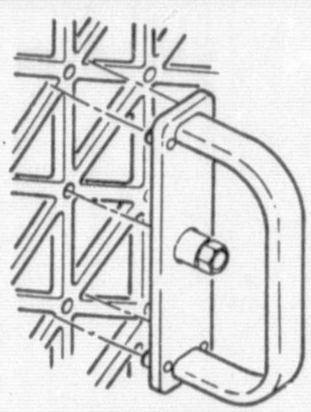
<table>
<tr><th>DESIGN PARAMETER</th><th>DESIGN REQUIREMENT/REMARKS</th></tr>
<tr><td>CROSS SECTIONS</td><td>The handholds/handrails will have a cross section with L/W ratio range of 1.66 to 3.00. The preferred L/W ratio is 2.00 with a corner radius of $\frac{W}{2}$.

L/W Ratio = 1.66 to 3.00
preferred L/W = 2.00
R = 1/2 W</td></tr>
<tr><td>SIZE</td><td>Sizing requirements of handholds/handrails for EVA and intravehicular activity (IVA) are shown in the accompanying table. Minimum grip length for EV handholds is 14.75 cm. (5.81 in.)
<table>
<tr><th rowspan="2">Activity</th><th colspan="2">L Dim (Min)</th><th colspan="2">L Dim (Max)</th></tr>
<tr><th>CM.</th><th>IN.</th><th>CM.</th><th>IN.</th></tr>
<tr><td>EVA</td><td>3.10</td><td>1.22</td><td rowspan="2">3.81</td><td rowspan="2">1.50</td></tr>
<tr><td>IVA</td><td>1.90</td><td>.75</td></tr>
</table></td></tr>
<tr><td>MOUNTING CLEARANCE</td><td>The minimum clearance distances between the lower surface of the handrail/handhold and the mounting surface are as shown:
<table>
<tr><th></th><th>cm.</th><th>in.</th></tr>
<tr><td>Extravehicular</td><td>5.72</td><td>2.25</td></tr>
<tr><td>Intravehicular</td><td>3.81</td><td>1.50</td></tr>
</table></td></tr>
<tr><td>SPACING FOR TRANSLATION</td><td>For extravehicular translation, handholds/handrails shall not be separated more than 122.0 cm. (48.0 in.).</td></tr>
<tr><td>SPACING FOR WORKSITES</td><td>Handholds/handrails spacing shall not exceed 45.8 cm. (18.0 in.) above or below the shoulder or 61.0 cm. (21.0 in.) to the left or right of the body centerline when working in a foot restrained position.</td></tr>
<tr><td>LOADING</td><td>1. Intravehicular handholds/handrails will be designed to a minimum ultimate load of 1113 newtons (250 lbs.) in any direction.
2. Extravehicular handholds/handrails will be designed to a minimum ultimate load of 1250 newtons (281 lbs.) in any direction.</td></tr>
<tr><td>TETHER ATTACHMENT</td><td>EVA handholds/handrails will accommodate flight EVA tether hooks at a spacing of 61.0 ± 12.7 cm. (24.0 ± 5.0 in.).</td></tr>
<tr><td>TETHER ATTACHMENT LOADING</td><td>1. Intravehicular handhold/handrail tether attach points will be designed to a minimum ultimate load of 1113 newtons (250 lbs.) in any direction.
2. Extravehicular handhold/handrail tether attach points will be designed to a minimum ultimate load of 3830 newtons (860 lbs.) in any direction.</td></tr>
<tr><td>GENERAL LOCATION</td><td>EVA handholds and handrails should be located to provide crewman protection from thermal, electrical, pyrotechnic, radiological, and electromagnetic equipment. Potentially dangerous equipment located within 30.5 cm. (12.0 in.) of the translation route or worksite will be identified in accordance with SC-M-0003. Thermal control shall be compatible with temperature specifications of the pressure garment assembly (PGA).</td></tr>
<tr><td>LIGHTING</td><td>EVA handholds/handrails shall be illuminated in accordance with SC-L-0002.</td></tr>
</table>

TABLE 2.6.1: Handhold and Handrail General Design Characteristics (Continued)

DESIGN PARAMETER	DESIGN REQUIREMENT/REMARKS
MATERIAL	Handholds and handrails are primarily fabricated from metals. Other rigid, semirigid, or cloth materials may be used in accordance with NHB 8060.1.
GRASP SURFACE	Handholds and handrails shall have a nonslip surface with no sharp edges or protrusions injurious to the crewman, PGA, or equipment.
COLOR	Color coding, lettering, or numbering systems may be used to assist in rapid identification. Colors shall be selected that minimize specular reflections and selected from FED-STD-595A and in accordance with SC-M-0003.



Portable handholds used on Skylab



Portable handhold mounting technique used in the Skylab Orbital Workshop (OWS). Technique requires a standard grid pattern for mounting. Similar grids may be used on the Shuttle Orbiter and payloads.

FIGURE 2.6-11: Portable Interior Handrail Used on Skylab Program

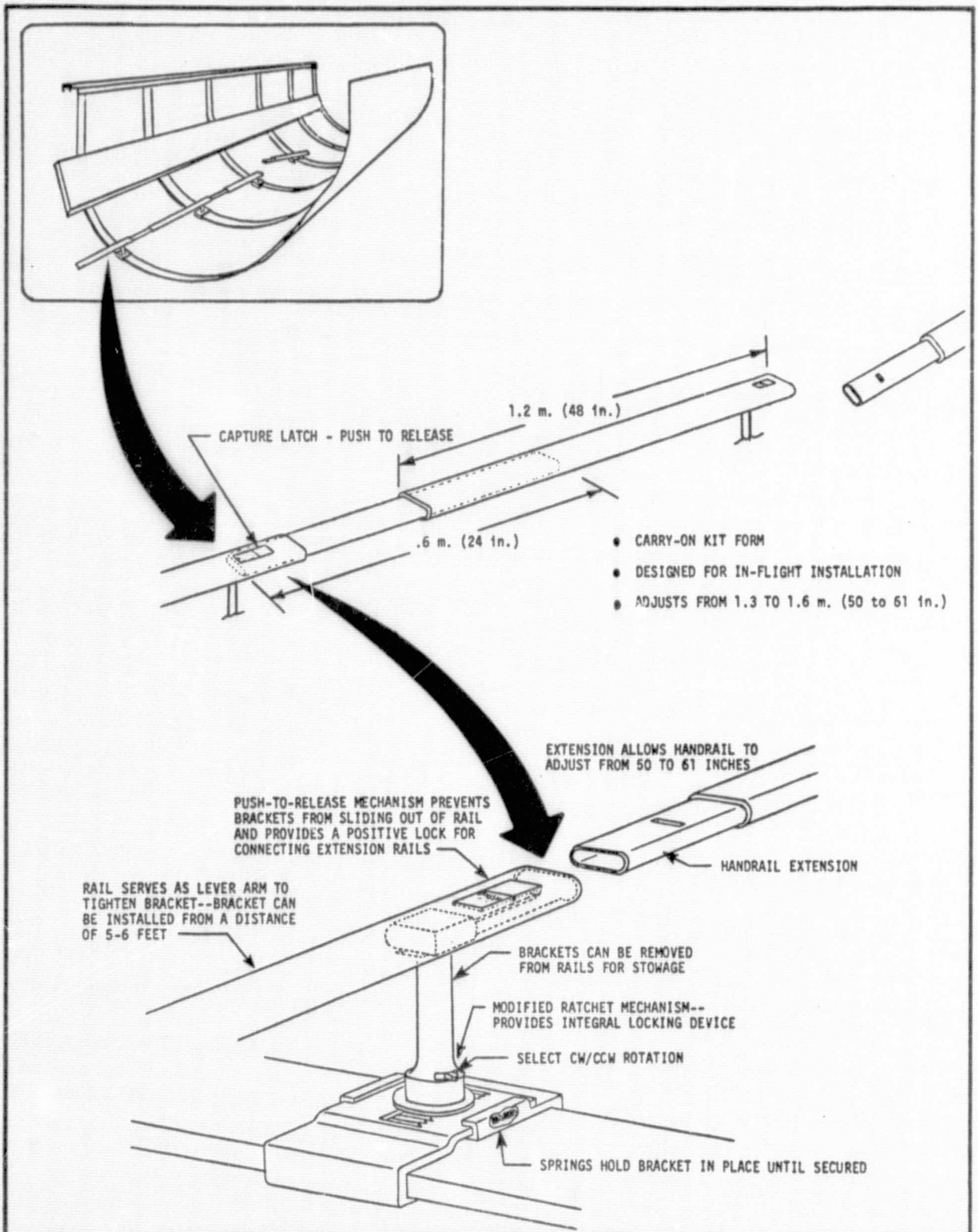


FIGURE 2.6-12: Portable EVA Handrail Conceptual Design

2.7 EVA RESTRAINTS AND WORKSTATIONS

2.7.1 Introduction

Crew and equipment restraints are required in the orbital "zero-gravity" environment for performing effective EVA's and to avoid the loss of equipment to free space. Each EVA crewman must be tethered to the Orbiter vehicle or payload where drifting into free space is possible--few exceptions are recognized. Among the exceptions are when manned maneuvering units (MMU's) are employed or in certain crew rescue operations from a disabled Orbiter. All "loose" EVA equipment, cargo and tools must be firmly secured or tethered at all times (i.e., either to the vehicle or EV crewman) during extravehicular transfer. However, when equipment is transferred between hard attach points by an EVA crewman in foot restraints, equipment tethering can be eliminated. Crew tethers are also required as a backup safety feature when working from foot restraints or workstations.

Several studies and hardware evaluations have been conducted during U. S. space programs to determine the requirement for EVA crew restraints and stabilization aids for various levels of task performance in weightlessness. The most versatile and efficient single restraint system developed to date for EV application is the foot restraint unit used during the Skylab Program. Only those EVA functions requiring little or no force application (e.g., inspection, monitor, diagnose) can be accomplished efficiently without foot restraints. Crew foot restraints have proven the most effective restraint units of those used on previous U. S. space programs and are baselined for Shuttle application.

EVA workstations are essentially foot restraints augmented with features such as ingress/egress aids, tether points, temporary equipment stowage hooks, tool stowage, auxiliary lighting, etc. as modular "add-on" items. The workstations are normally classified as either dedicated or portable workstations. Dedicated EVA workstations are fixed at the worksite specifically to service a payload or Orbiter system as a planned EVA function.

Portable EVA workstations are modular units transportable by the EVA crewman to various worksites while on-orbit and readily attached/detached to several structural configurations. Portable EVA workstations are being studied for Shuttle Orbiter/payload application; however, a configuration was not baselined as of early 1976.

2.7.2 Shuttle Baseline EVA Restraint Systems

Restraint articles for use during Shuttle extravehicular activities will consist primarily of foot restraints, crew and equipment tethers and portable EV workstations. The basic foot restraint configuration used on the Skylab Program is baselined for Shuttle application. Crew and equipment tethers (although not currently baselined) similar to the Skylab units will also be used on the Shuttle Orbiter. Several tether hook configurations may be used for compatibility with various structural and spacesuit interfaces. The portable EVA workstation concepts under study by NASA will consist primarily of a base plate with integrated Skylab type foot restraints and a complement of modular subsystems to support diverse worksite requirements. The EVA workstations may be transported on-orbit by the EVA crewman (i.e., handcarried), Remote Manipulator System (RMS) or Manned Maneuvering Unit (MMU) to support payload operations. The workstations will be designed to attach to a variety of Orbiter and payload structural/subsystem elements.

2.7.3 EVA Crew Foot Restraints

The crew foot restraints baselined for Shuttle application are simple in design, lightweight and provide positive restraint at all body attitudes. The restraints, Figure 2.7-1, are basically a pair of toe bars and heel fittings mounted to a flat honeycomb base plate or other compatible structure. Machined boot fittings are provided on the space suit boots to interface with the restraint system, Figure 2.7-2. The toe of the boot is placed under the toe bar and the foot pivoted to insert the heel into the restraint. The foot restraint fixture and the mating boot interface fitting are passive elements with tolerance built into the system to prevent heel

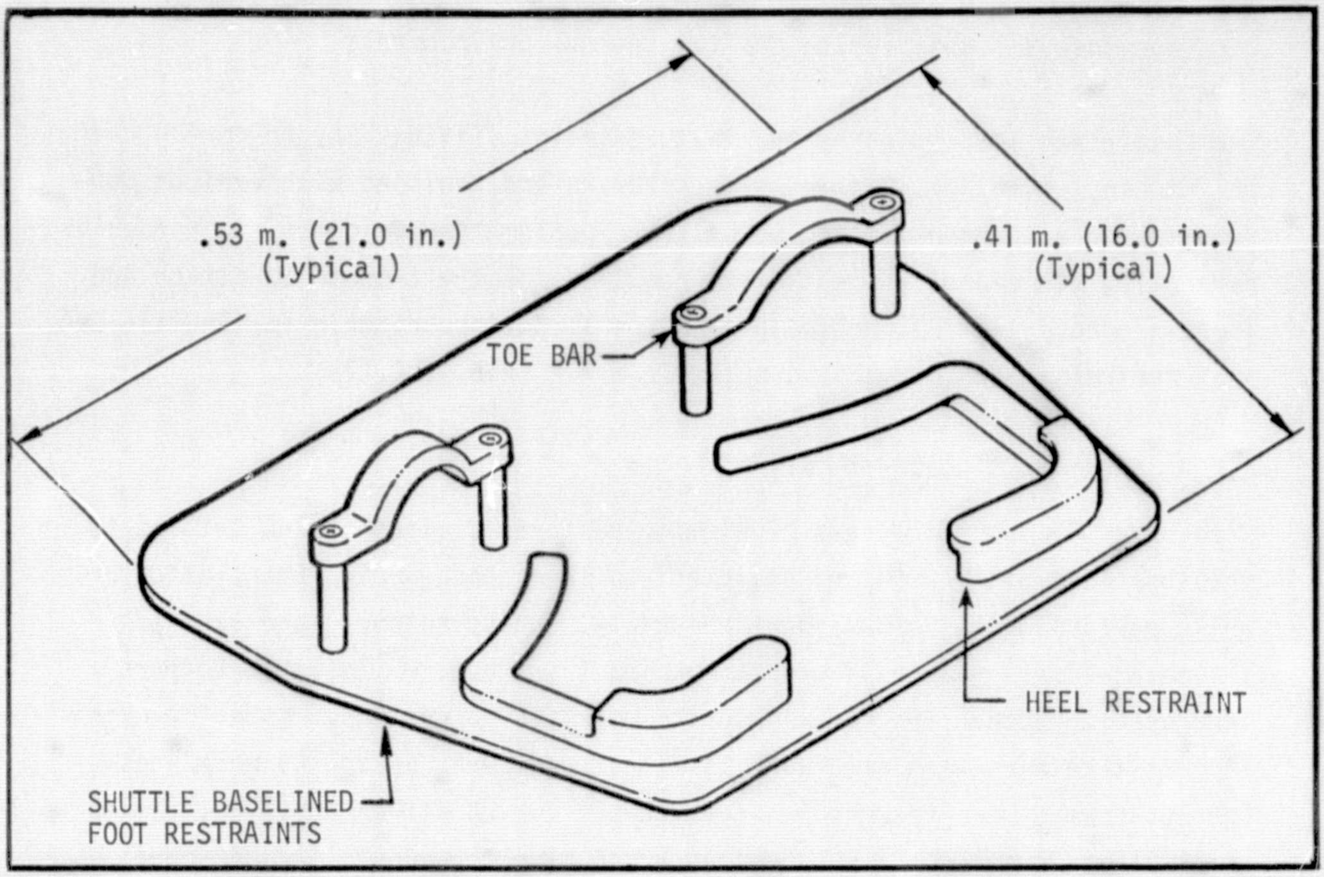


FIGURE 2.7-1: Space Shuttle Extravehicular Foot Restraints

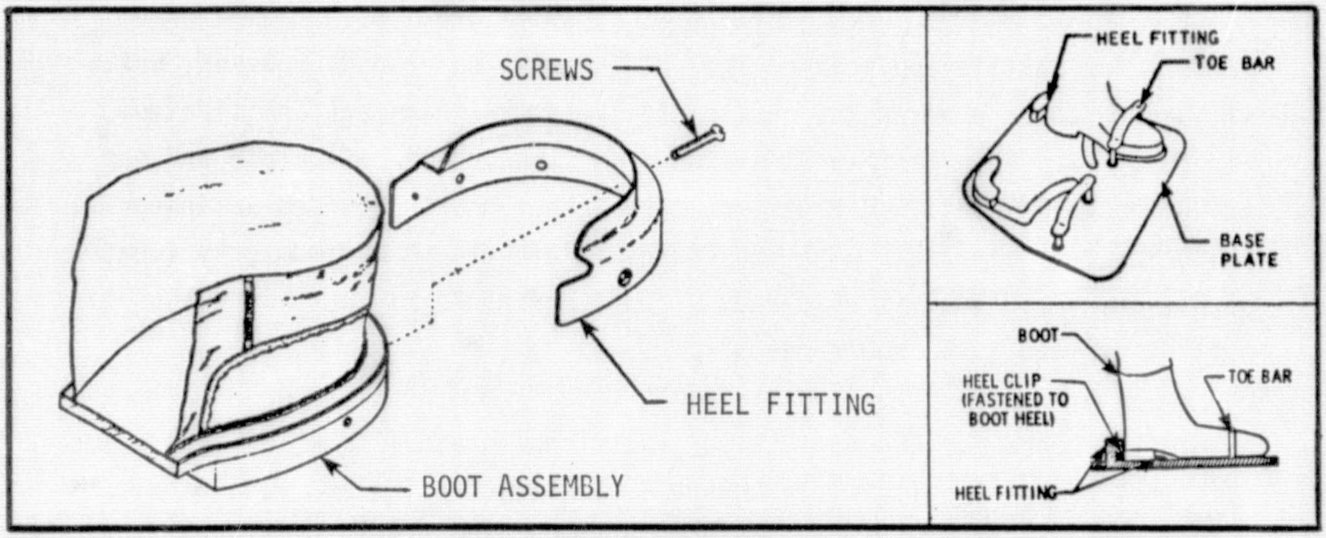


FIGURE 2.7-2: Spacesuit Boot-to-Foot Restraint Interface

binding under all anticipated orbital thermal environments.

The base plate for attaching the foot restraint fittings may be configured to interface with specific worksite hardware and equipped with various subsystems for attachment at the worksite. Supplementary aids (e.g., handholds, handrails, structural elements) are required for the crewman to attach and ingress/egress the foot restraints. General design criteria for Shuttle EVA foot restraints are summarized in Table 2.7.1 (Ref. 2.7.1).

2.7.4 Shuttle EVA Tethers

Previous U.S. space programs have employed three classes of EVA tethers to preclude loss of crewmen and equipment to free space during translation or while performing tasks outside the vehicle. Wrist tethers were used to secure equipment to the EV crewman during transport, while waist tethers were used to tether the crewman during worksite activities. Both the wrist and waist tethers were also used to tether equipment at the EV worksites. The EV crewmen were tethered to the vehicle during all external activities (orbital and transearth) on previous space flights. Dedicated personnel tethers or tethers integral to the life support system umbilical were employed. With the exception of MMU operation remote from the Orbiter, the Shuttle EVA crewmen will be tethered at all times while outside the vehicle.

Tethers for Shuttle application are not formally baselined; however, units similar to those used on the Apollo and Skylab Programs are anticipated, Figure 2.7-3. The flexible straps were constructed of Beta cloth and the tether hooks primarily of alumimum. The tether hooks provided an integral handgrip area compatible with the spacesuit gloves. A minimum grip length of 9.5 cm. (3.75 in.) is required. The tether hooks may vary in design to satisfy various task requirements.

All tether hooks for EVA application must incorporate a latching mechanisms such that the hook will freely engage to an attach point but require a positive action to release. Each hook will provide a latch lock that the

TABLE 2.7.1: EV Foot Restraint General Specifications

DESIGN PARAMETER	DESIGN REQUIREMENTS/REMARKS
SECURITY	EVA foot restraints shall maintain foot position to allow the crewman a complete range of motion (roll, pitch, yaw) within the constraints of the spacesuit.
RESTRAINT SPACING	• Center to center distance = 25.4 to 43.2 cm. (10.0 to 17.0 in.). • Center dimension shall be determined from analysis of the tasks to be performed.
LOAD CAPACITY	• Ultimate design load = 623 N. (140 lbs.) min. in tension and shear. • Torsion = 203 N-m (1800 in-lb) min.
TEMPERATURE (LOCATION)	Maximum allowable temperature for EVA foot restraints shall be compatible with the space suit being used.
LOCATION	Foot restraints shall be located at all EVA and IVA worksites requiring performance of the following tasks: • Repetitive tasks requiring the use of one or both hands • Long term monitoring tasks • Tasks requiring close control of body position
HAZARDS	Foot restraints located within 30.5 cm. (12 in.) of equipment where failure would cause injury to the crewman will be identified in accordance with SC-M-0003. Potential areas of damage to flight equipment by the crewman will also be identified.
MATERIAL	Metals shall be the primary material for foot restraint fabrication. Other rigid or semirigid materials may be used when warranted by design constraints. Materials must be approved in accordance with NHB 8060.1.

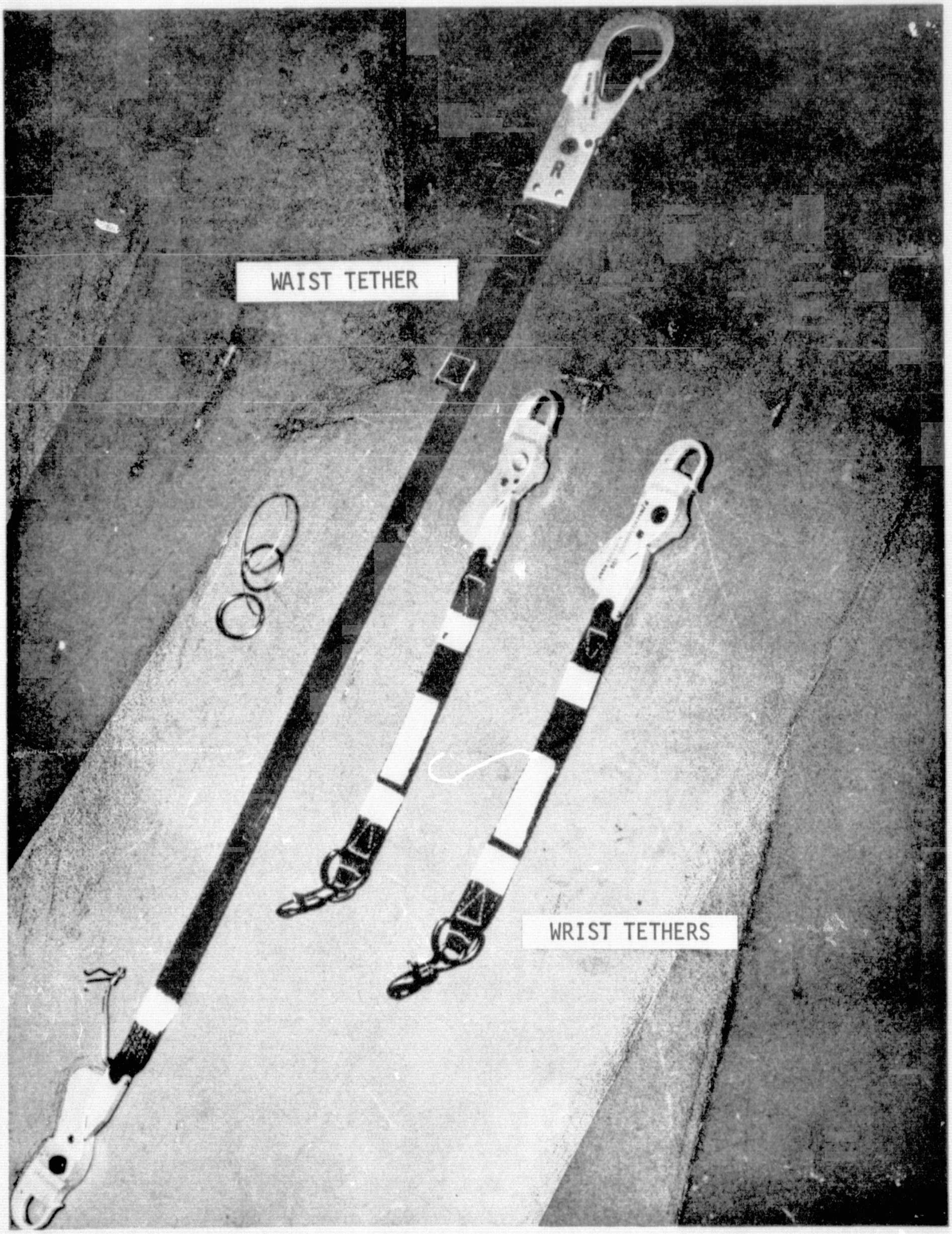


FIGURE 2.7-3: Wrist and Waist Tethers Used on Skylab Program

crewman may engage to prevent the hook from being inadvertently released. The latch lock will incorporate engage/disengage nomenclature to indicate a locked-unlocked status. All operations associated with the tether hooks must be operational with one EVA gloved hand. The hooks are normally designed to preclude side loading.

Although EVA tethers for the Shuttle Program were not baselined during this study, Table 2.7.2 provides general tether design data (wrist and waist) for Skylab tethers and is intended for reader familiarization only. Design/configuration data relative to Shuttle EVA personnel tethers for payload bay activities were not available for documenting in this report.

2.7.5 Shuttle EVA Workstations

The crewman must be restrained during all orbital EV operations requiring force applications or when monitoring payload activities for extended periods at a worksite. EV worksites are designated as planned or unplanned. Planned worksites are established during systems design including the operations to be performed. The worksite incorporates all restraint systems, interfaces, controls and displays, and lighting requirements to perform the planned EVA tasks. Unplanned EV worksites are locations where the crewman terminates translation to perform unscheduled or contingency tasks. The locations are determined immediately prior to or during the EVA. Fixed dedicated workstations have been used for most planned extravehicular activities on previous U.S. space programs.

The development of multimission Space Shuttle vehicles and the increasing number of planned and potential payload EVA applications indicate the need for a versatile, portable restraint/workstation system to support orbital operations. Modular EVA workstations are under study by the NASA Johnson Space Center to accommodate a variety of EV operational, maintenance and repair functions in the payload bay. A basic portable EVA workstation concept being studied/evaluated for the Shuttle Program is depicted in Figure 2.7-4. The workstation consists primarily of basic foot restraints,

TABLE 2.7.2: General Tether Design Specifications

	WRIST		WAIST	
	S.I.	Conventional	S.I.	Conventional
WEIGHT	.174 kg.	.38 lb.	.226 kg.	.5 lb.
STRAP LENGTH	25.4 cm.	≈10 in.	N/A	N/A
OVERALL LENGTH	N/A	N/A	124 cm.	≈48 in.
LOAD CAPABILITY*	2610 N.	585 lbs.	2610 N.	585 lbs.
STRAP MATERIAL	Beta Cloth		Beta Cloth	
TETHER HOOK MATERIAL	Aluminum		Aluminum	
TRIGGER SNAP MATERIAL	Brass		--	

* Along longitudinal axis

fold-out aids to assist crewman ingress/egress, temporary stowage fixtures for equipment handling and a means of attaching the workstation at the worksite. The final EVA workstation(s) baselined for the Shuttle Program may vary from the configuration shown in Figure 2.7-4. The crew ingress aids and method of attachment may be varied to meet specific worksite structural configurations. Payloads employing planned EVA experiment operations requiring tasks to be performed at several worksites may best utilize an integrated EVA workstation as configured in Figure 2.7-5. Passive interfaces would be required at each payload worksite to attach the workstation. The foot restraints are identical for all workstation concepts.

Methods of attaching the portable EVA workstation units at payload worksites and to various structural configurations are being studied by the NASA. Possible concepts may include a "universal" attachment clamp to interface with EV handrails and standard structural shapes (Figure 2.7-6), adhesive pads for on-orbit remote (e.g., free-flying satellite) application

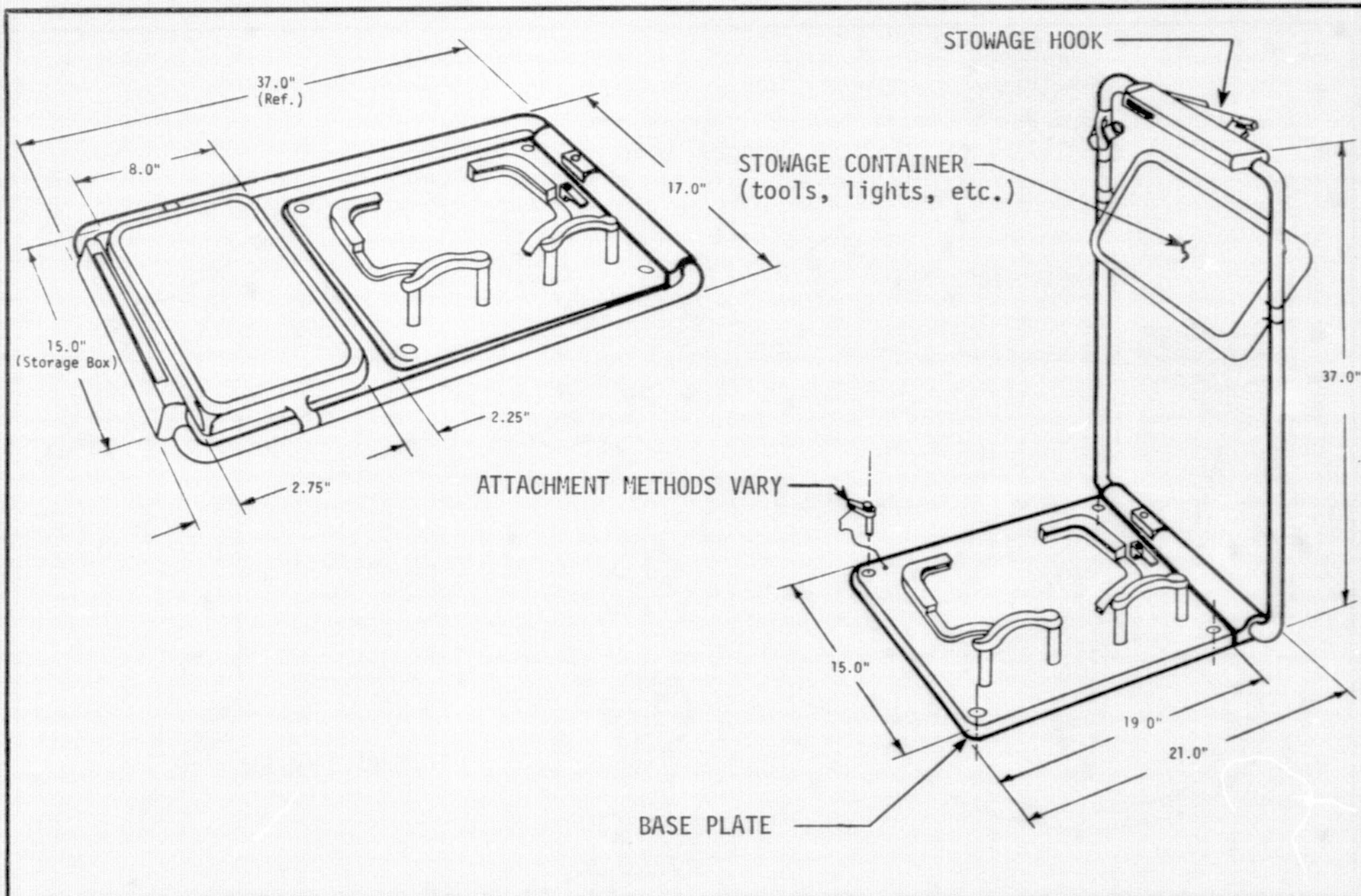


FIGURE 2.7-4: Portable EVA Workstation Concept (Conceptual Design Only)

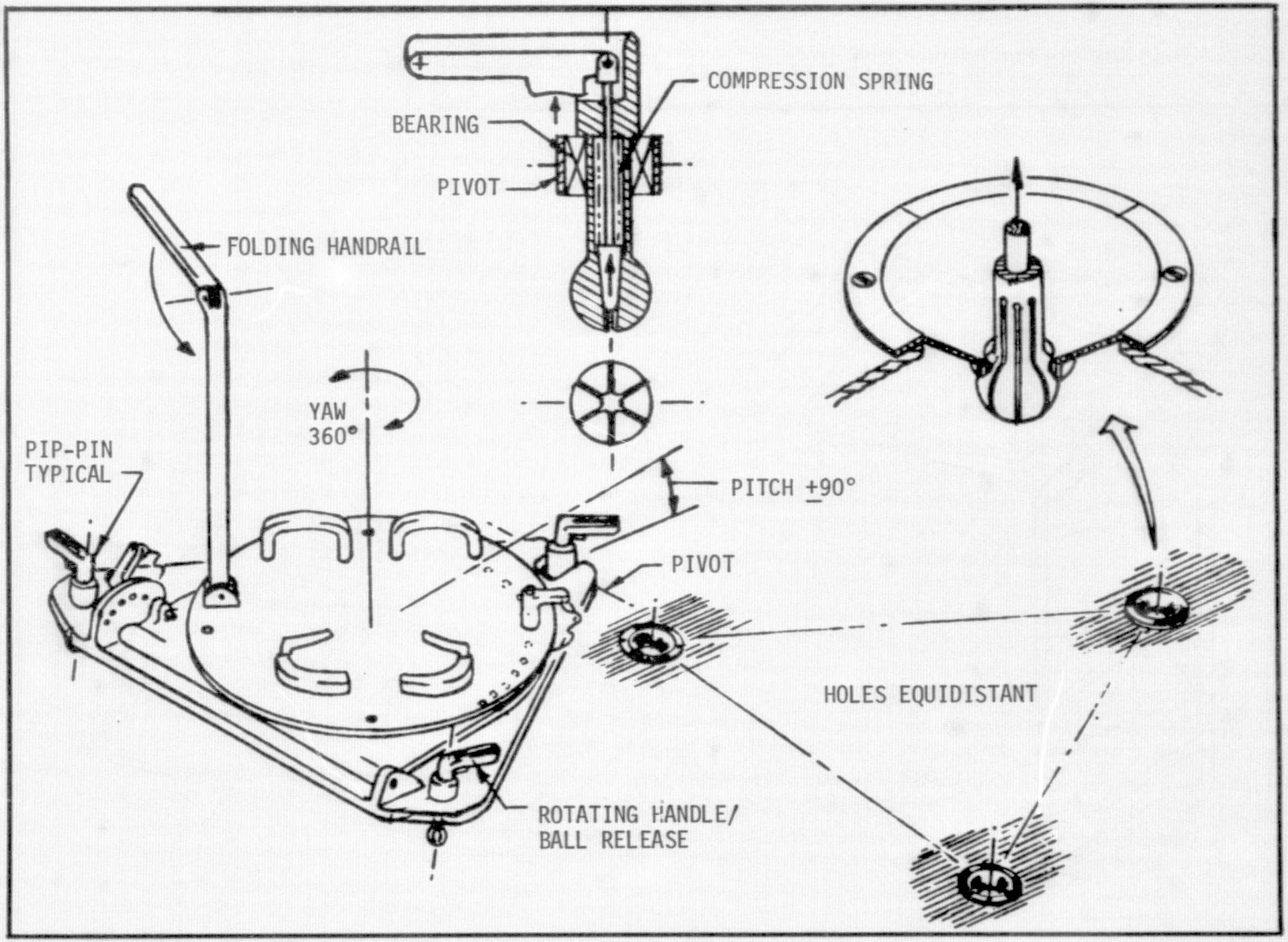


FIGURE 2.7-5: Integrated EVA Workstation Concept (Conceptual Design Only)

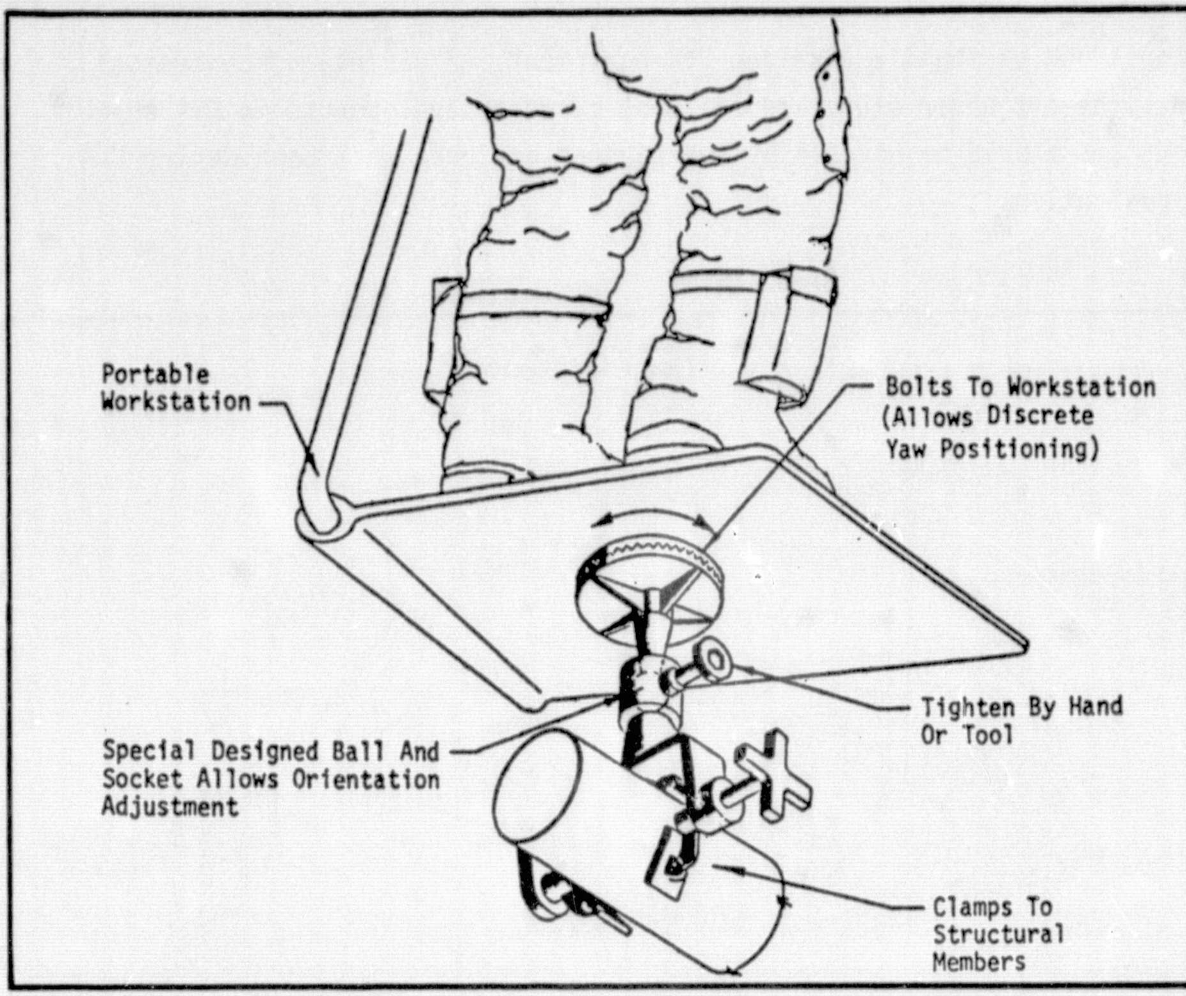


FIGURE 2.7-6: EVA Workstation Attachment Concept (Conceptual Design Only)

to flat surfaces (Figure 2.7-7), or a simple hole pattern to accept quick-release fasteners (Ref 2.7.2). Standard workstations attachment methods and corresponding worksite interfaces will be developed as EV support hardware for planned EVA functions. The EV crewmen may be required to select an appropriate workstation attachment fixture from stowage following worksite inspection when conducting unscheduled or contingency EVA.

To iterate, the EVA workstations and attachment illustrations depicted in this section (Section 2.7, EVA Restraints and Workstations) are possible concepts developed by the NASA and NASA contractors only and should not be

construed as Shuttle baseline EVA equipment. A variety of conceptual designs are under study and the most current developments in EVA support systems should be studied by the payload designer when considering EVA applications.

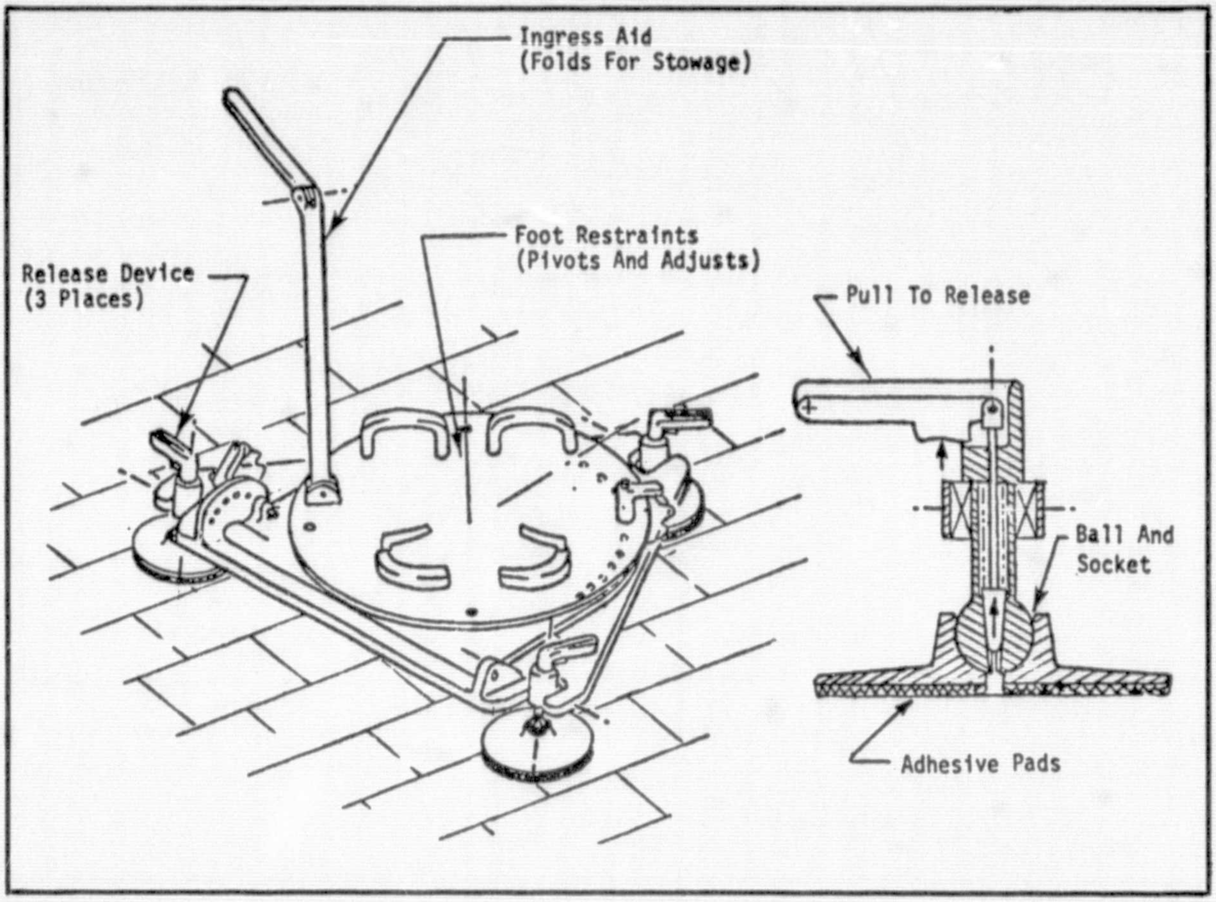


FIGURE 2.7-7: Portable EVA Workstation Adhesive Attachment (Concept Only)

SECTION 2.7 REFERENCES

2.7.1 Manned Spaceflight Extravehicular/Intravehicular Activity Support Equipment, General Specifications, NASA - Manned Spacecraft Center, SC-E-0006, December, 1972.

2.7.2 Neutral Buoyancy Test Report, Portable EVA Work Station Evaluation, NASA Johnson Space Center, February 3, 1975.

2.7.3 Development of An EVA Cost Model, Volume II, Shuttle Orbiter Crew and Equipment Translation Concepts and EVA Workstation Concept Development And Integration, URS/Matrix Company, Final Report, January 1975.

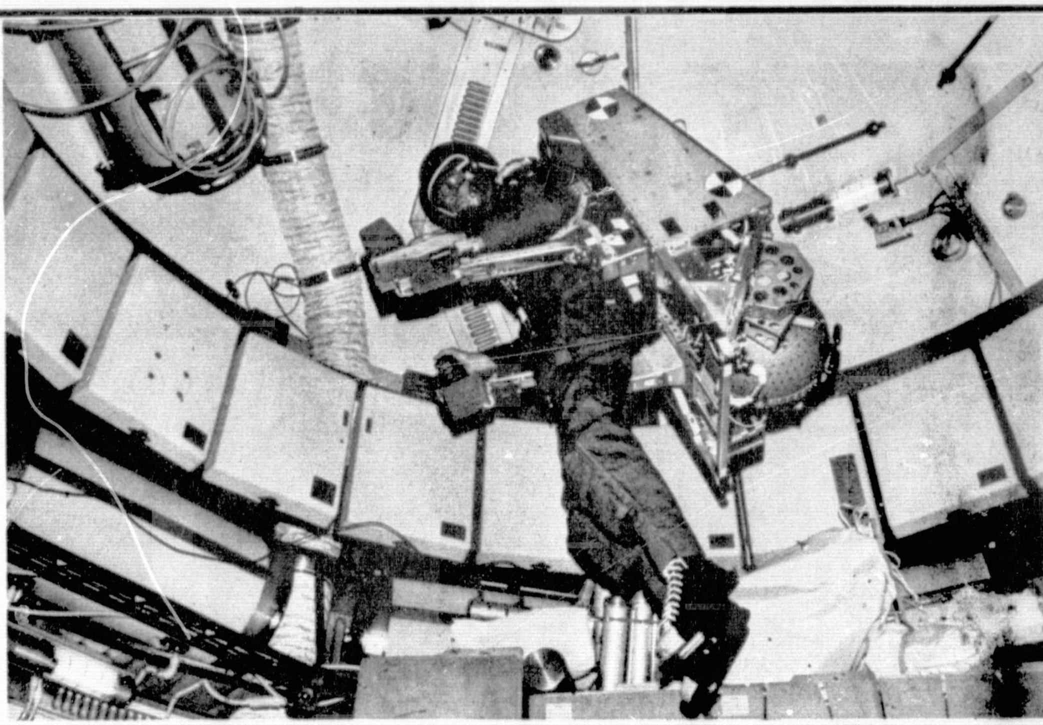
2.8 MANNED MANEUVERING UNIT

2.8.1 Introduction

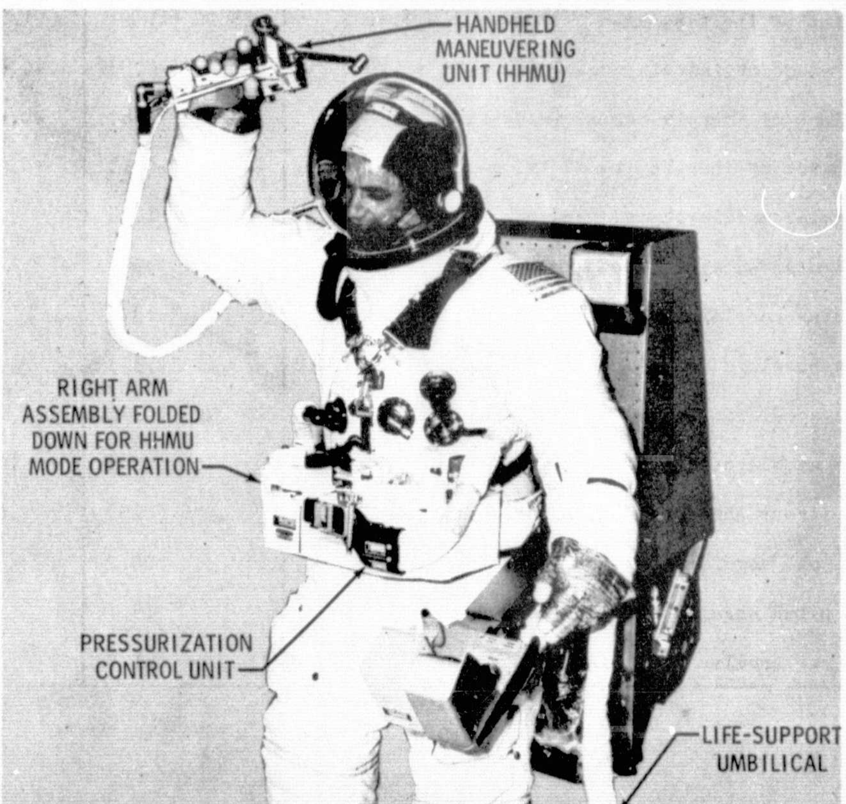
Research projects beginning with the U. S. Gemini Program have investigated various methods to provide an independent free-flying maneuvering capability for crewmen during extravehicular activities. Astronaut Maneuvering Units (AMU's) were developed by the U. S. Air Force for evaluation during the Gemini Program as Experiment D012. However, only limited evaluations were conducted with the Gemini units. Skylab Experiment M509 followed the earlier maneuvering unit developments and consisted of a backpack mounted control system designated as the Automatically Stabilized Maneuvering Unit (ASMU) and a hand-held thruster system called the Hand-Held Maneuvering Unit (HHMU). The systems as flown on the Skylab Program are shown in Figure 2.8-1.

The ASMU, a predecessor to the Shuttle Manned Maneuvering Unit (MMU), was evaluated within the Skylab pressurized Orbital Workshop. Emphasis was placed on obtaining both man and maneuvering unit data for development and integration of control sensors, control laws, actuators and man-machine interfaces. Eleven (11) evaluation runs were conducted during the Skylab Program following prescribed on-orbit flight maneuvering procedures. Approximately 14 hours of flight time were logged which included 8 shirt-sleeve and 3 spacesuit runs (Ref. 2.8.1). These tests demonstrated precise position and velocity control and the overall utility of an autonomous maneuvering capability.

The Skylab maneuvering unit evaluations generated quantities of reliable data for analysis of the system as an integrated unit, support equipment requirements, control modes and human performance aspects (Ref. 2.8.2). The results of the Skylab evaluations and extensive ground-based testing were considered sufficient to qualify the basic maneuvering system, supporting subsystems and controls as operational hardware for Space Shuttle application. The following subsections describe the Manned Maneuvering Unit proposed for the Space Shuttle Program.



AUTOMATICALLY STABILIZED MANEUVERING UNIT MODE



HAND HELD MANEUVERING UNIT MODE

FIGURE 2.8-1: Skylab M509 Maneuvering Unit Experiment

2.8.2 Shuttle Manned Maneuvering Unit Studies

A versatile, utility-type maneuvering unit for Space Shuttle application is under study by the NASA. Conceptual designs are scheduled for completion in early 1976, followed by detail component design in late 1976, with operational MMU's available in December 1980. The MMU backpack device, used in conjunction with the Shuttle Extravehicular Mobility Unit (EMU)--see Section 2.2, will permit EVA crewmembers to maneuver in space independent of spacecraft systems. Potential Shuttle MMU applications include backup system to the Shuttle Remote Manipulator System (RMS), retrieval and deployment of small satellites, on-orbit servicing of contamination-sensitive payloads, assembly of large space structures, personnel rescue and many potential payload servicing functions.

2.8.3 Space Shuttle MMU

The Shuttle MMU will provide an extravehicular crewman with the capability to maneuver in the immediate vicinity of an orbiting spacecraft with control in six degrees of freedom. The MMU readily attaches to the primary life support system (PLSS) of the Shuttle Extravehicular Mobility Unit to provide a completely autonomous free-flying system. The MMU contains a cold gas propulsion system, batteries, control electronics, gyroscopes, hand-controllers, and controls and displays to support EVA operations. A flight support station located in the payload bay facilitates stowage, servicing, and don/doff activities. The current design concept of the Shuttle MMU is shown in Figure 2.8-2. Preliminary overall dimensions and MMU reference coordinate system are depicted in Figure 2.8-3.

Baseline Shuttle MMU program requirements (preliminary) are listed below (Refs. 2.8.3 and 2.8.4):

- Modular backpack device readily attached to the Shuttle EMU
- Operate in the immediate vicinity of the Shuttle Orbiter--100 m. (330 ft.) nominal range from Orbiter (early applications only)
- One man don, doff and service while EVA

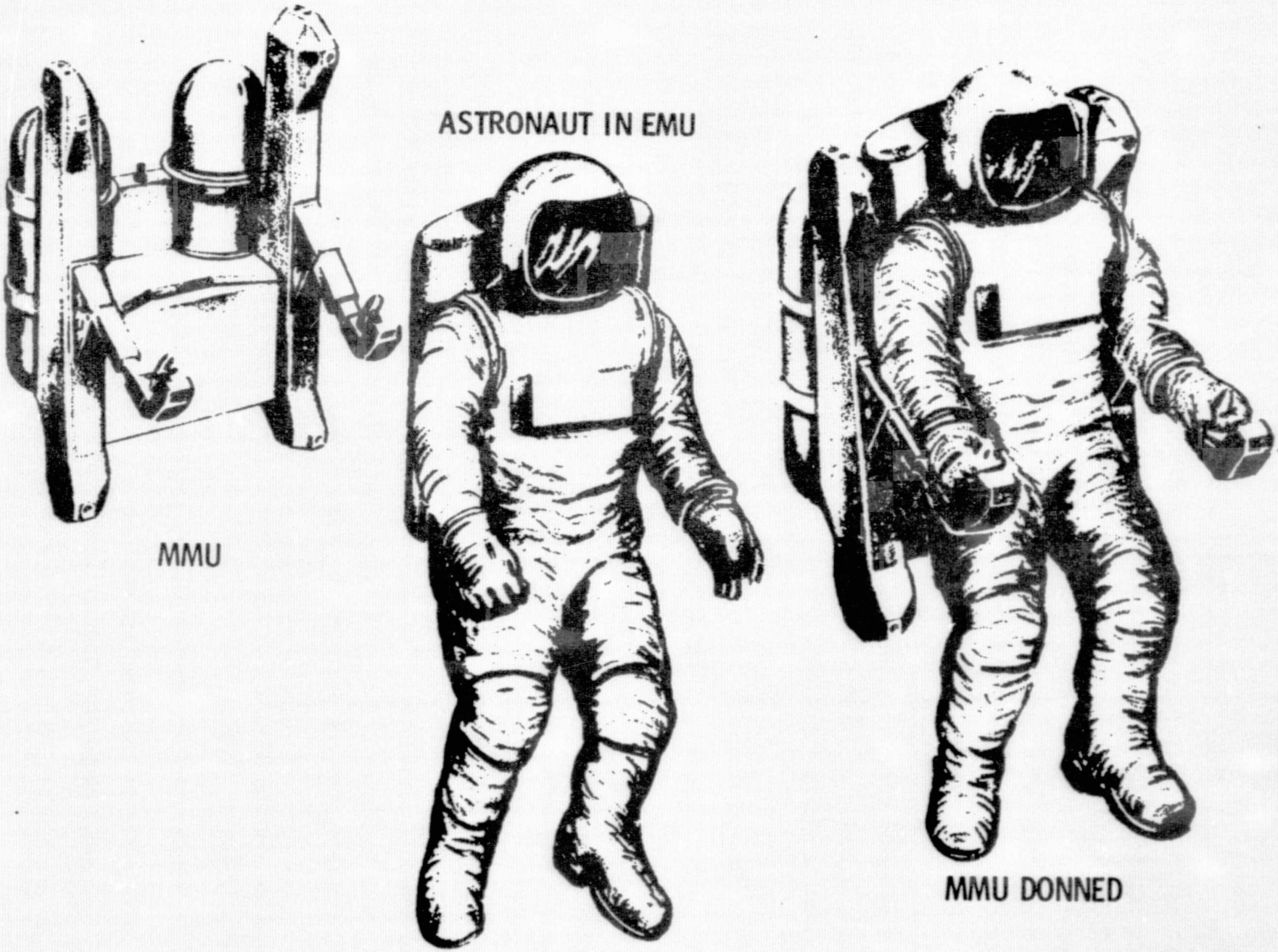


FIGURE 2.8-2: Design Concept for Shuttle Manned Maneuvering Unit

- Fail safe (sufficient redundancy for safe return to the Orbiter after one failure)
- Support a 6.5 hour EVA
- Propellant: Non-contaminating gaseous nitrogen (GN_2)
- Control: Automatic attitude hold with manual rate command
- Delta Velocity: 20.1 m/sec (66 ft/sec) per charge (minimum)
- Flight Support Station (FSS) in payload bay for retention of MMU during launch, on-orbit don/doff, service and entry
- No umbilicals to Orbiter during operation (safety tethers may be used during early testing)
- Provisions for mounting movie or TV cameras, tools, etc.
- Electrical power outlet (20 Vdc, 2 amps) for flood lights
- Provisions for attaching to a worksite or for transporting cargo
- Six degrees of freedom control authority
- Spacecraft-type piloting logic

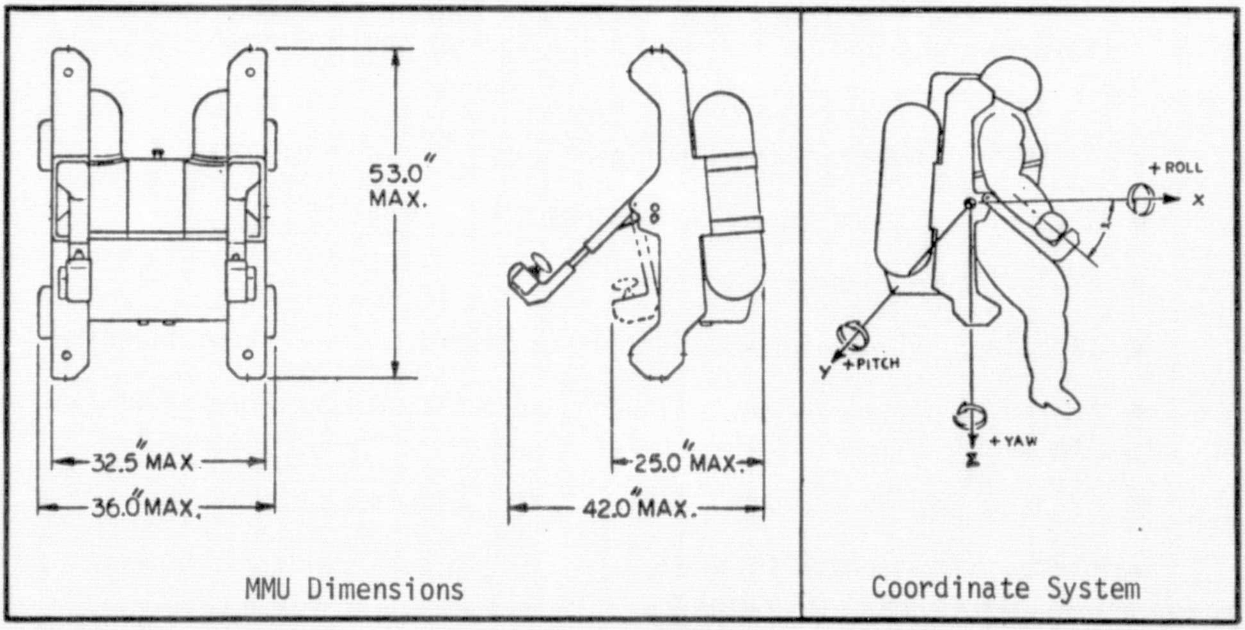


FIGURE 2.8-3: MMU Overall Dimensions and Reference Coordinates (Preliminary)

- Attitude hold
  - Automatic attitude hold prime (rate gyros)
    - (a) Rate deadband: $\pm$ 2 degrees/sec
    - (b) Displacement deadband: $\pm$ .2 degrees/sec
  - Manual attitude control backup (pilot selectable)
  - Provision for pilot to inhibit automatic attitude hold (docking, worksite activity, etc.)
- Rotation control: acceleration command (10 $\pm$ 3 degrees/sec^2)
- Translation control: acceleration command (.1 $\pm$ .01 m/sec^2) (.3 $\pm$ .05 ft/sec^2)
- Propellant capacity: 11 m/sec (36 ft/sec) per tank--total 72 ft/sec. at 211 kg/cm^2 (3000 psi)
- Thruster operation cue required
- Weight:
  - MMU: 89 kg. (196 lbs.) Dry
  - Total: 127 kg. (280 lbs.) maximum including Flight Support Station
  - Man and EMU hardware: 191 kg. (425 lbs.)--baseline weight using 95 percentile suited man

Requirements for interfacing the MMU to the Shuttle Orbiter and/or payloads were defined as follows:

- Avionics: none currently defined
- Electrical: none currently defined
- Fluid: none currently defined
- Lighting: Flight Support Station to make use of existing lighting
- Mechanical (payload bay): launch, on-orbit, return storage in payload bay
- Transfer of MMU through 1.0 m. (40 in.) diameter hatch
- Contingency stowage in cabin.

The MMU will hard mount directly to the Shuttle EMU life support systems

through mechanical attachment provisions. Display requirements including caution and warning will be provided by the Shuttle EMU system.

The Shuttle MMU design will be fail-safe in which the failure of any single hardware item will not preclude the ability of the crewman to return to the spacecraft. The normal operating mode utilizes two separate systems operating in parallel that are completely isolated from each other in electrical, propulsion and control logic. Either system can be used separately in a backup/contingency capacity. Each isolated system contains a pressure vessel, propulsion system, battery, power distribution and control logic.

Shuttle MMU candidate operational modes and potential applications are discussed in Section 3.5 of this document.

2.8.4 MMU Support Equipment

MMU Flight Support Stations (FSS's) can be mounted in the payload bay, one on each side, to support stowage, servicing and don/doff functions. The FSS provides interfaces for MMU propellant recharge, exchange of expendable packages, and the capability for an unassisted crewman in EMU gear to don, doff, and service the MMU, Figure 2.8-4. Design of the FSS will provide fail-safe release (doffing) of the crewman and EMU when stowing the MMU, Figure 2.8-5. Preliminary overall dimensions of the FSS are shown in Figure 2.8-6.

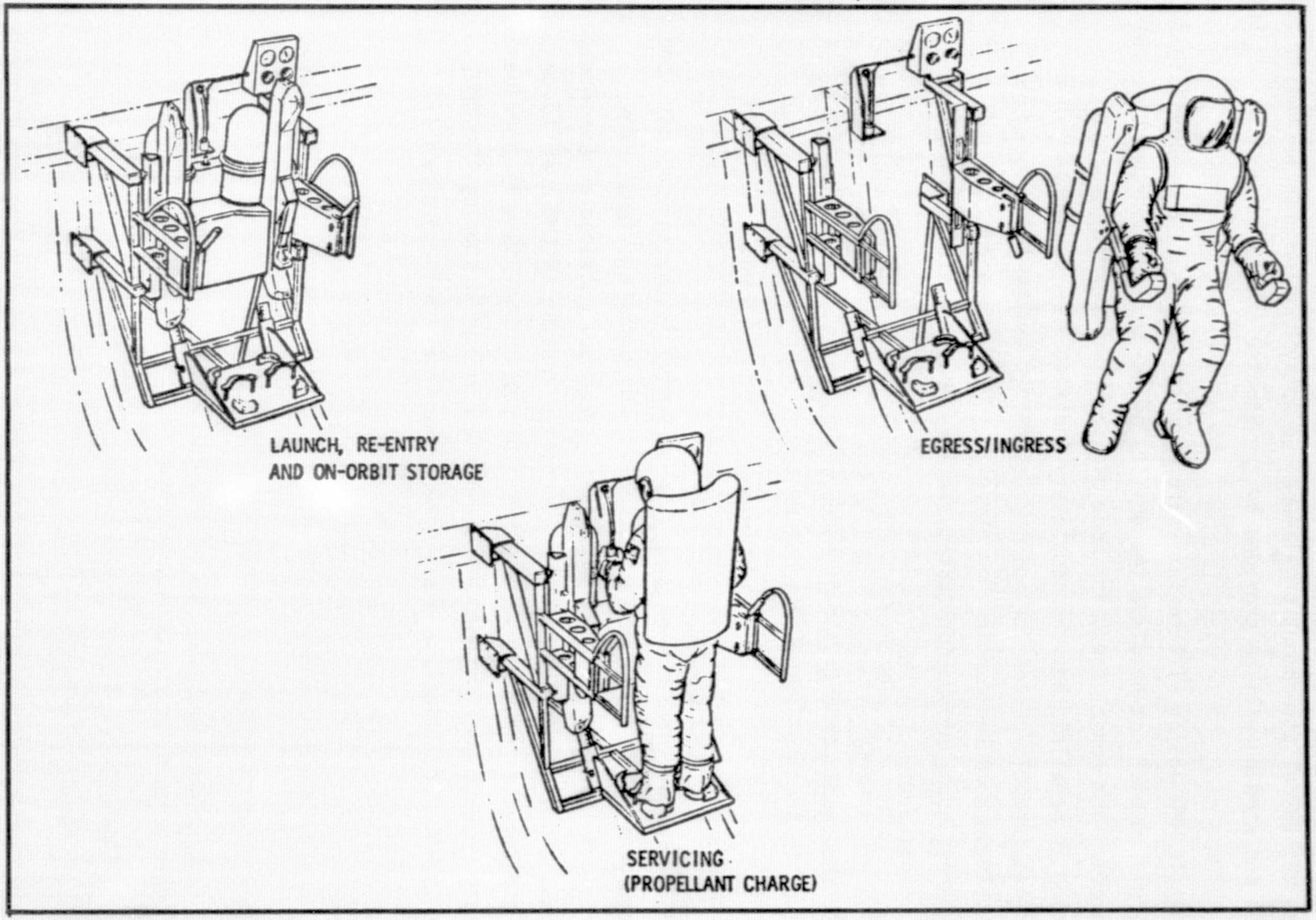


FIGURE 2.8-4: Manned Maneuvering Unit Flight Support Station

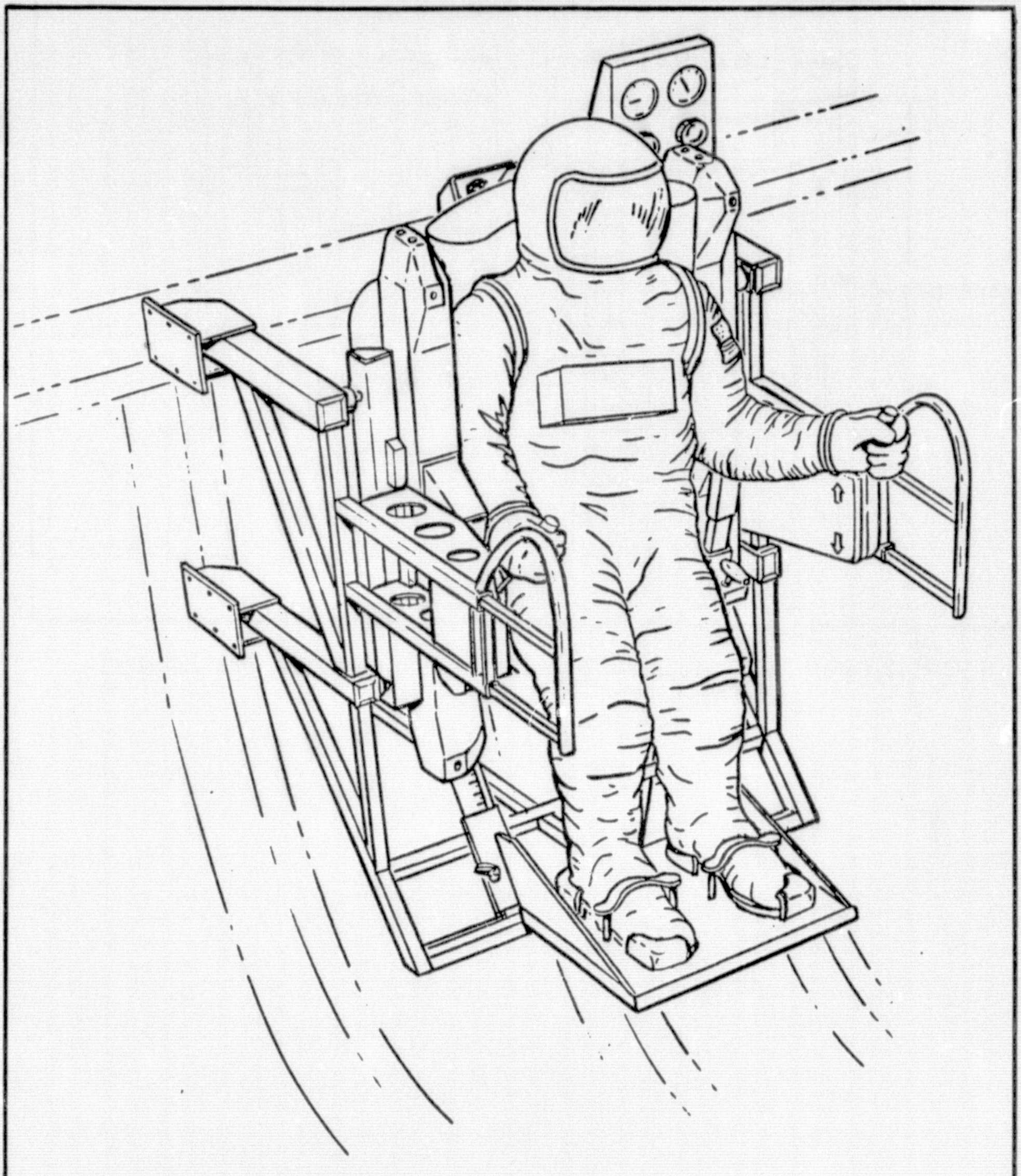


FIGURE 2.8-5: MMU Doffing at the Flight Support Station

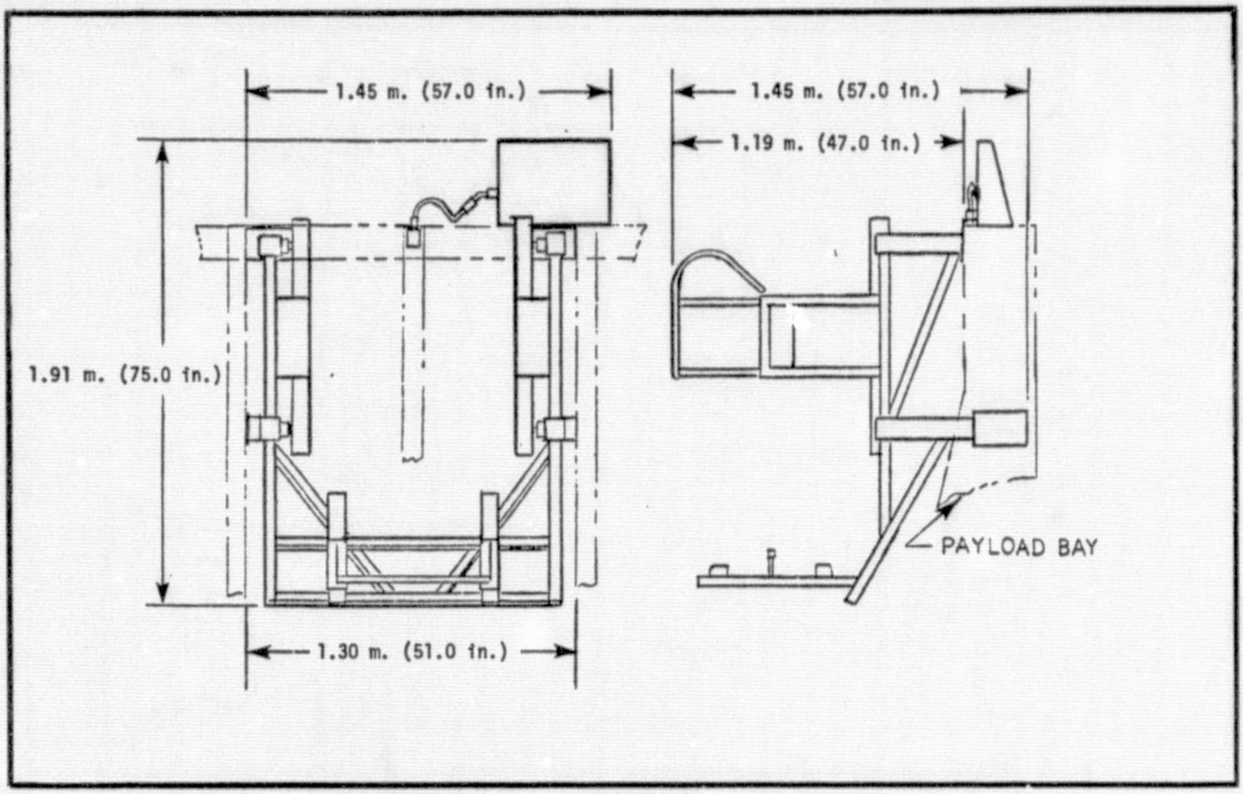


FIGURE 2.8-6: Flight Support System Overall Dimensions (Preliminary)

SECTION 2.8 REFERENCES

2.8.1 Whitsett, C. E., and B. McCandless II. "Astronaut Maneuvering Equipment Orbital Test Results and Future Applications," American Astronautical Society Twentieth Annual Meeting, Los Angeles, California, Paper AAS74-137, August 20-22, 1974.

2.8.2 Martin Marietta Corporation: Astronaut Maneuvering Equipment M509 Hardware Assessment Report, JSC-05547, Contract NAS 8-24000, June 1974.

2.8.3 NASA: Request For Proposal (RFP) No. 9-BC732-81-5-74P, Statement Of Work for Manned Maneuvering Unit Preliminary Design.

2.8.4 Martin Marietta Corporation: Manned Maneuvering Unit System Design Specification, Contract No. NAS 9-14593, MCR-75-398, Rev. B, April 5, 1976.

2.9 EVA TOOLS AND SUPPORT EQUIPMENT

2.9.1 Introduction

The Shuttle Orbiter will provide a general purpose combination Orbiter and payload tool kit compatible with both extravehicular and intravehicular requirements and environments. The general purpose tool kit will consist primarily of off-the-shelf hand tools modified to provide tether attachment and improved EV gloved hand grip capabilities. Several special tools for unique application either in the Orbiter crew cabin or the payload bay are being studied. Additional supporting equipment including 16 mm, 35 mm and TV cameras, binoculars, spotmeter, and associated accessories are available for EVA related operations.

The inclusion of metric/Whitworth tools for payload support is being considered. The metric tool kit would be available as a payload unique kit, used as required, and would not impose a weight penalty on all payloads. The tool finishes and lubricants will be compatible with the extravehicular environment and payload contamination prevention requirements.

2.9.2 Standard Tool List

A standard tool list of "off-the shelf" tools was approved by the NASA for Shuttle Orbiter intravehicular and extravehicular use (Ref. 2.9.1). The standard tool list is provided in Table 2.9.1. The tool list should be used as a guide by planners and designers in selecting fasteners and developing crew interfaces for specific functions. Tools for either Orbiter or payload support required on each flight will be selected from the list. The function for which the tool is used shall be approved by the NASA. The tools listed may be superseded with replacement/additional tools as Orbiter and payload development progress. However, tool additions to the proposed list shall be approved by the NASA.

2.9.3 Special Tools

Dedicated tools designated for specific Orbiter applications will be studied

TABLE 2.9.1: Shuttle Standard Tools--Candidate

TOOL	NOMENCLATURE	DIMENSION/SIZE
Ratchet wrench	Micrometer type adjustment, quick release button	3/8" square drive, 10" overall length
Universal joint		3/8" square drive x 3/8" square drive
Spinner		3/8" square drive x 3/8" square drive
Ratchet extension		4", 3/8" square drive x 3/8" square drive
Ratchet extension		8", 3/8" square drive x 3/8" square drive
Ratchet extension		12", 3/8" square drive x 3/8" square drive
Socket set	12 point flank drive, standard depth	3/8" square drive, 1/4" through 1-1/8" in 1/16" increments
Adapter		3/8" square drive to 1/2" square drive
Socket set	12 point flank drive	3/8" square drive, 1/4" through 1-1/8" in 1/16" increments
Hex socket		3/8" square drive, .75 shank length
Phillips sockets		3/8" square drive, 1.50 shank length

TABLE 2.9.1: Shuttle Standard Tools--Candidate (continued)

TOOL	NOMENCLATURE	DIMENSION/SIZE
Torque set sockets		3/8" square drive, 1.50 shank length
Screw driver	Interchangeable shaft/tips (slot/phillips), square shaft	.032 x 3/16 slot/no. 2 phillips x 2" shaft
		.037 x 1/2 slot/no. 1 phillips x 2" shaft
		.050 x 3/8 slot/no. 3 phillips x 2" shaft
		.060 x 5/32 slot/no. 4 phillips x 2" shaft
Screw driver	Interchangeable shaft/tip (slot/phillips), square shaft	.032 x 1/2 slot/no. 1 phillips x 7" shaft
Screw driver	90^{0} off-set	Phillips no. 3 & 4 (tips) x 6" shaft
		Phillips no. 1 & 2 (tips) x 6" shaft
		Slot (.032 x 3/16) x (.037 x 1/2) slot x 6" shaft
		Slot (.050 x 3/8) x (.060 x 5/32) slot x 6" shaft
Double end flare nut wrench set	12 point flank drive, openings set at 15^{0} angle, heads offset 15^{0}, different size at each end	1/4" through 1-1/8" in 1/16" increments

TABLE 2.9.1: Shuttle Standard Tools--Candidate (continued)

TOOL	NOMENCLATURE	DIMENSION/SIZE
Torque wrench	Micrometer type adjustment, quick release button	0-150 in-lbs., 3/8" drive, 10" overall length
Pliers	Multi-purpose electrical plier tip, wire cutter, stripper and bolt cutter, crimp stations (insulated)	Wire sizes 22 through 10 bolt sizes, 4-40 through 10-24
Pliers	Needle nose pliers, pin straighteners with side cutters	6-1/2" overall, 2-3/16" serrated jaws, 1/16 tip
Pliers	Vise grip	1-5/8" jaws x 10" length
Connector pliers		
Pinch bar		16" length x 5/8" diameter
Hammer--Ball pen		12 oz. x 12" handle
Scissors		
Tin snips	Wiss side cutter	4"
Chain wrench	Vise grip	8", chain 19" working perimeter
Vise	Clamp on type, serrated jaws	6" jaw width x 8" jaw spread
Diagonal cutter	High leverage type	7-1/4" x 3/4" jaws
Adjustable wrench	Thin profile (crescent type)	12" x 1-5/16" jaws

individually as requirements are identified. However, a primary goal regarding tool interfaces is the design of Orbiter and payload equipment that requires only standard, commerically available hand tools. Candidate special tool requirements currently identified for Orbiter crew cabin and payload bay operations are listed in Table 2.9.2 (Ref. 2.9.1). The special tools identified for use outside the pressurized cabin are for correction of equipment anomalies only and are not for planned EVA operations. The special tools, however, may be used for payload functions in unscheduled and contingency EVA situations. In addition to the special tools listed in Table 2.9.2, it is anticipated that other tools will be required as Orbiter and payload subsystems are developed.

A backup kit for manually closing the payload bay doors in the event of a malfunction is proposed for the Orbiter. The kit tentatively consists of the following:

- Portable, battery-powered hack saw
- Come-along (hoist type device)
- Lock pins
- Pry bar
- Wire
- Hammer

TABLE 2.9.2: Shuttle Special Tools--Candidate

TOOL	NOMENCLATURE	DIMENSION/SIZE
Modular stowage container installation/removal tool		1/4" square drive, 23" shaft x 5/32" allen head drive tip
LRU black box installation/removal torque wrench extension tool	Chain driven torque wrench extension	1/4" square drive x 20" shaft length
Loop pin removal/installation tool	TBD	TBD
Side hatch actuation/TPS removal tool	TBD	TBD
Radiator deploy/retract mechanism actuation tool	TBD	TBD

2.9.4 Tool Development Consideration

If special hand or power tools are required by the payloads, consideration should be given to utilizing previous designs or modifications to meet Shuttle payload requirements. Several reduced-reaction power tools were developed and evaluated for use on previous space programs. Although none of the special power tools were employed in past U.S. space programs, Shuttle payload designs may identify specific requirements. Previously developed tools that may have application to Shuttle payloads include a bolt installation and removal tool, space power tool D-16, and a spin torque tool, shown in Figures 2.9-1 through 2.9-3. Power tools may be advantageous in highly repetitive tasks requiring arm, wrist, and hand motions (e.g., series of threaded fasteners removal/replacement) that tend to fatigue the spacesuited crewman. Additional multiple-function "space" tools developed during previous U.S. space programs with possible Shuttle application are listed below:

- Inertia Wheel
  (NASA-Marshall Space Flight Center)
- Space Impact Tool
  (Winchester Arms Company)
- Tube Swaging Device
  (NASA-Langley Research Center)
- Space Tool Mitten
  (Hanover Industrial Machine Company)
- Bonding and Electroadhesor Tools
  (Chrysler Corporation Space Division)
  (National Cash Register Company)
- Gas Leak and Pressure Detection Tools
- Welders
  (United Aircraft Corporation)
  (Westinghouse Electric Corporation).

Characteristics of the space tools listed above, including additional tool concepts, are contained in Reference 2.9.2. The capability of the EVA crewman and the scope of EV payload tasks may be extended with the use of

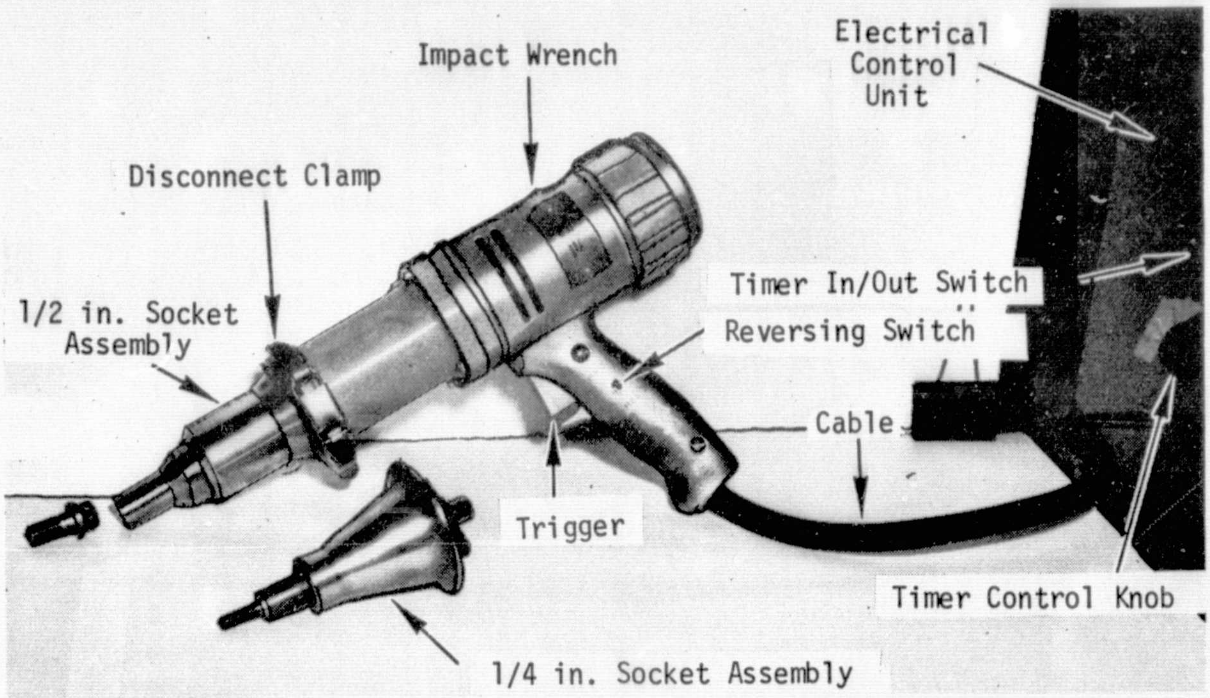


FIGURE 2.9-1: Bolt Installation and Removal Tool
(Aerojet-General Corporation)

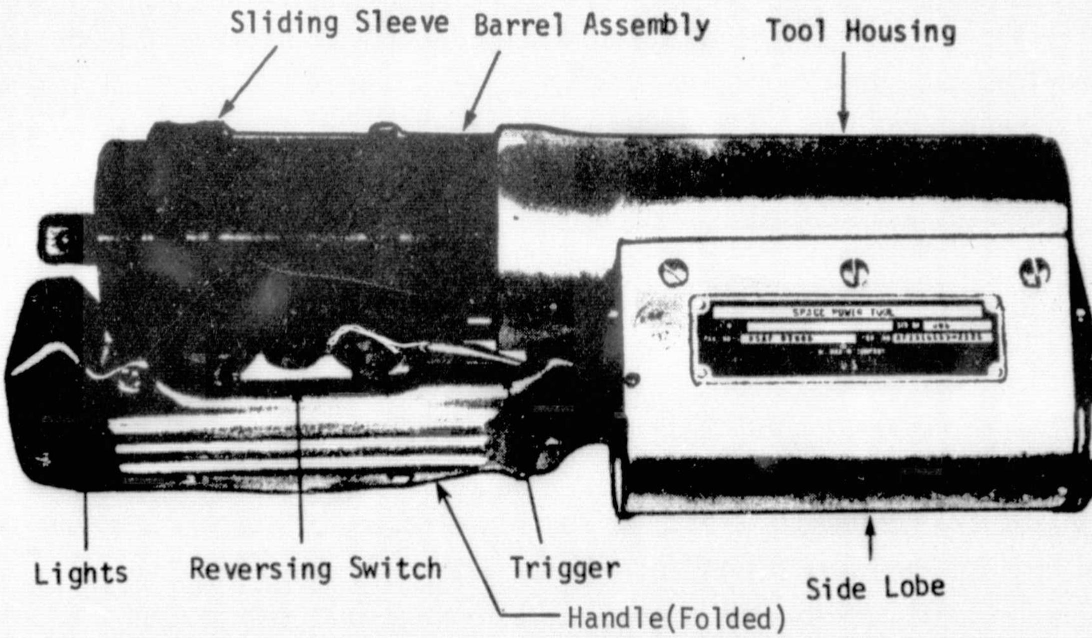


FIGURE 2.9-2: Space Power Tool D-16 (Martin Marietta Company)

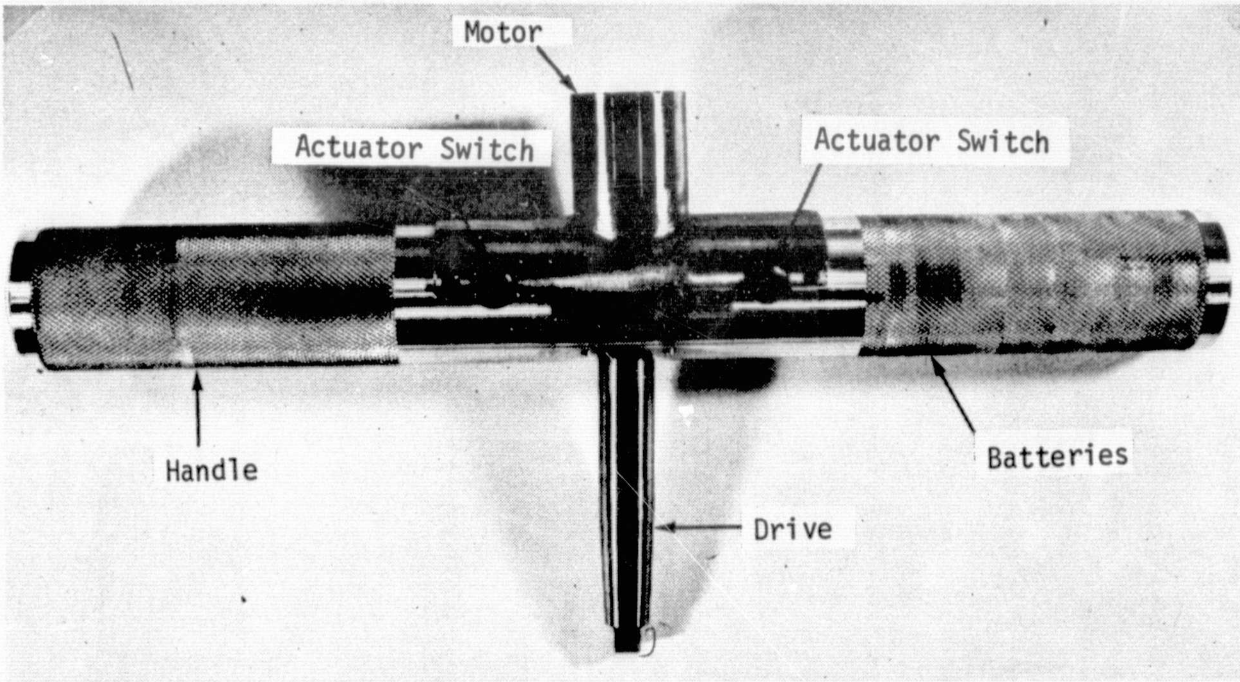


FIGURE 2.9-3: Spin Torque Tool (NASA-Marshall Space Flight Center)

power tools -- given the proper man-machine interface. However, a survey of previous tool development activities is recommended prior to initiating costly special tool development. In considering special tools for Shuttle use, particulate generating tools will require particle collection provisions to avoid contamination and crewmember health hazards.

2.9.5 Shuttle Standard Tool Kit

A standard tool kit will be flown on each Shuttle mission and contain a basic complement of hand tools selected from the standard tool list. The contents and size of the tool kit will not be defined until Shuttle subsystems are further developed to ensure selection of appropriate tools. It is anticipated that the kit will contain ratchet wrenches, extension drivers, sockets, screwdrivers, etc. encased in a tool set pouch (Ref. 2.9.3). A typical tool pouch is illustrated in Figure 2.9-4; all

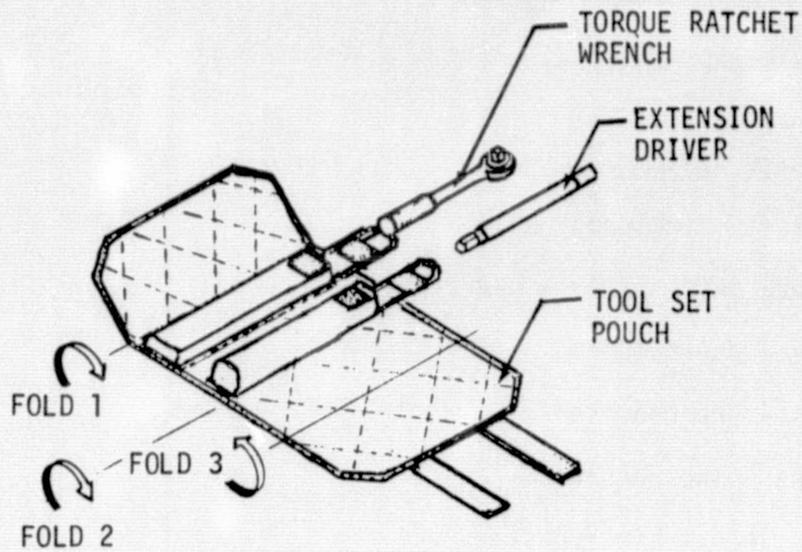


FIGURE 2.9-4: Shuttle Tool Kit Pouch Concept

tools to be stored in the pouch are not shown in the illustration.

2.9.6 Camera and Associated Equipment

Shuttle provided equipment in addition to hand tools that may be used to support payload EVA operations includes 16 mm and 35 mm camera systems, tape recorder, TV camera kit, and binoculars. The system/kit contents are listed in the following subsections.

2.9.6.1 Camera System

The 16 mm Camera System includes:

- 16 mm camera - one required
- 16 mm magazines - five required
- camera bracket - one required

- 16 mm power cable - one required
- 16 mm power pack - one required
- 25 mm lens - one required.

2.9.6.2 <u>35 mm Camera System</u>

The 35 mm Camera System includes:

- 35 mm camera and battery - one required
- 35 mm lens - one required
- 55 mm lens - one required
- 135 mm lens - one required
- 35 mm magazines - six required.

2.9.6.3 <u>TV Camera System</u>

The TV Camera System includes:

- TV camera - one required
- TV power cable - one required
- TV monitor and cable - one required
- TV zoom lens - one required
- TV ring sight - one required
- TV camera bracket - one required.

2.9.6.4 <u>Ancillary Shuttle Equipment</u>

Other items available for EVA related operations include:

- Tape recorder - one required
- Tape recorder casettes - 20 required
- Tape recorder battery - seven required.

- Spotmeter - one required
- Binoculars - one required.

2.9.7 Shuttle Tool and Support Equipment Stowage

The tools and support equipment identified will be stored in the forward portion of the Orbiter mid-deck directly opposite the airlock hatch (Figure 2.9-5). Individual stowage locker layouts are illustrated in Figures 2.9-6 through 2.9-9.

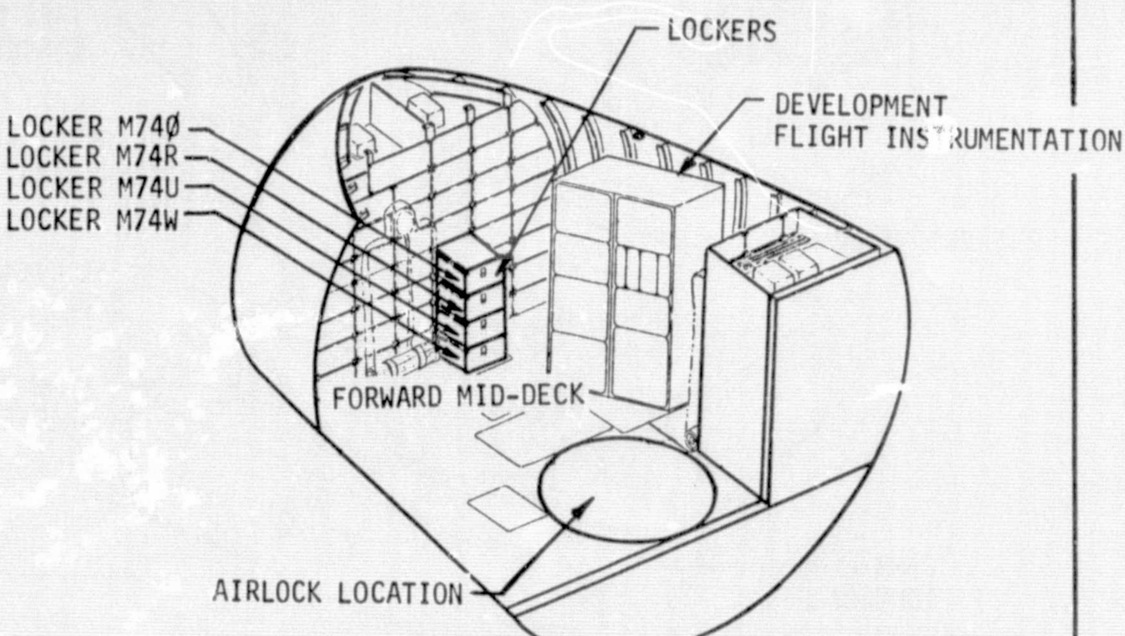


FIGURE 2.9-5: Orbiter Stowage Area For Special Tools and Equipment

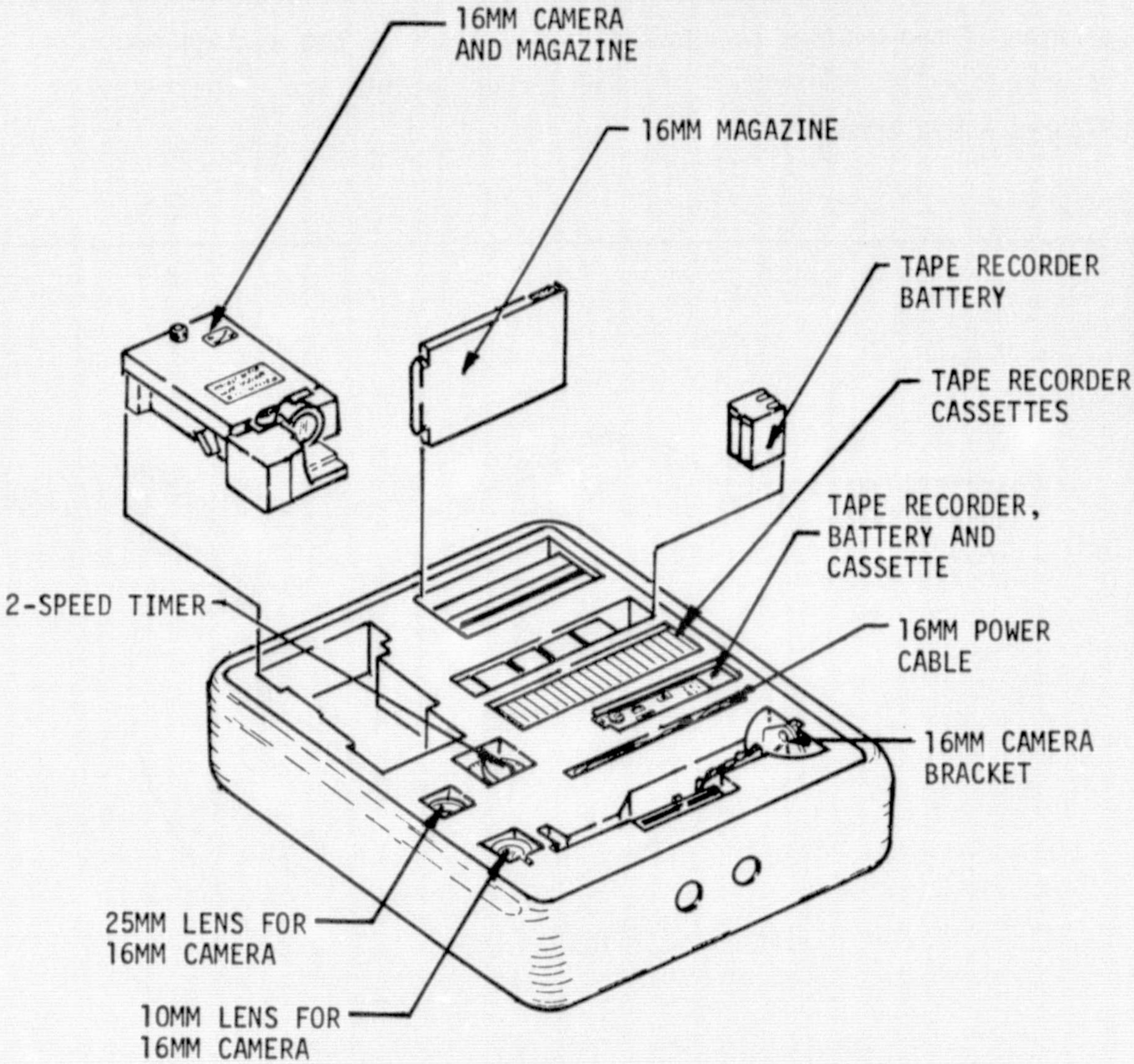


FIGURE 2.9-6: Stowage Locker M74Ø (Top)

SPACE SHUTTLE EVA

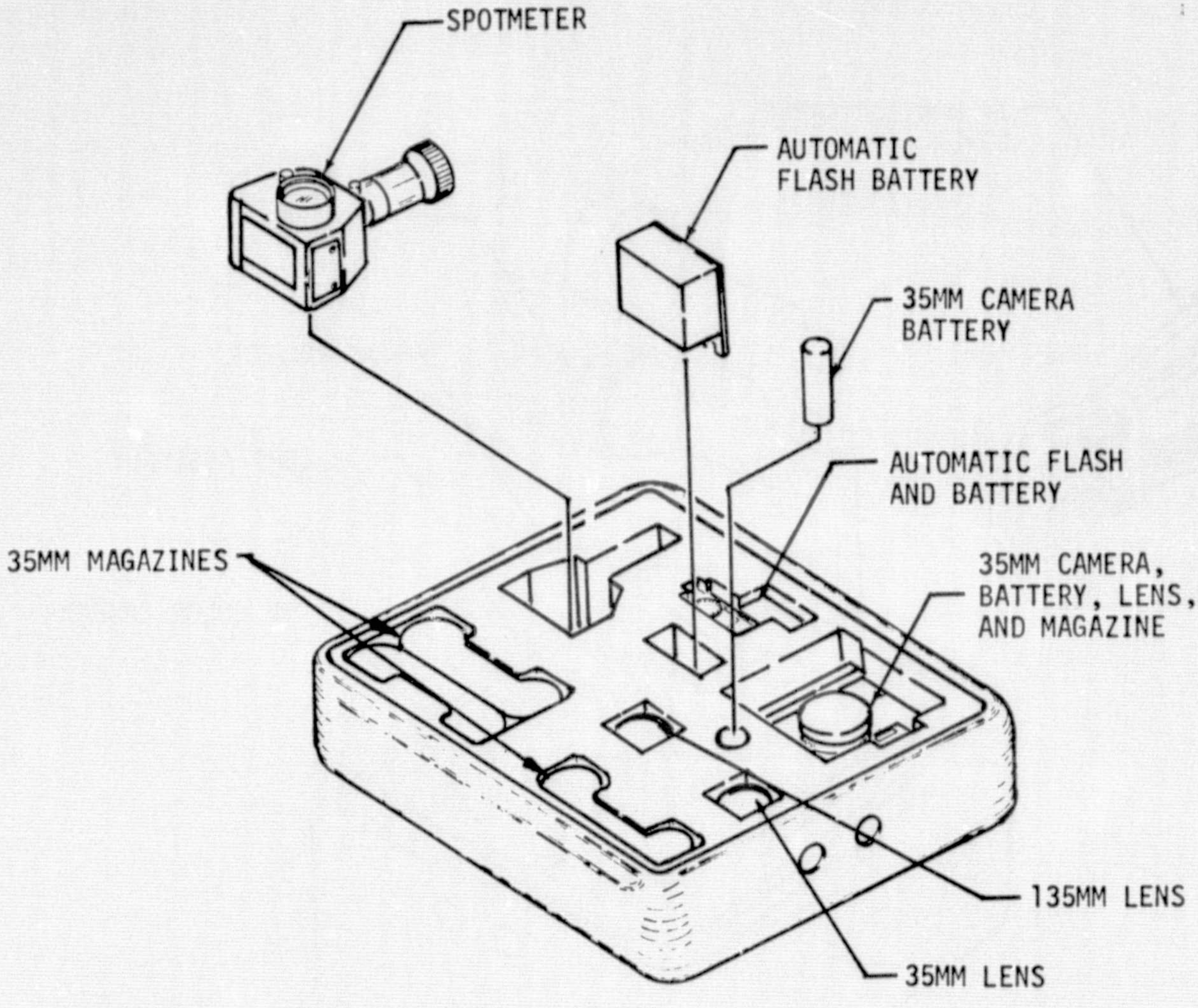


FIGURE 2.9-7: Stowage Locker M740 (Bottom)

SPACE SHUTTLE EVA

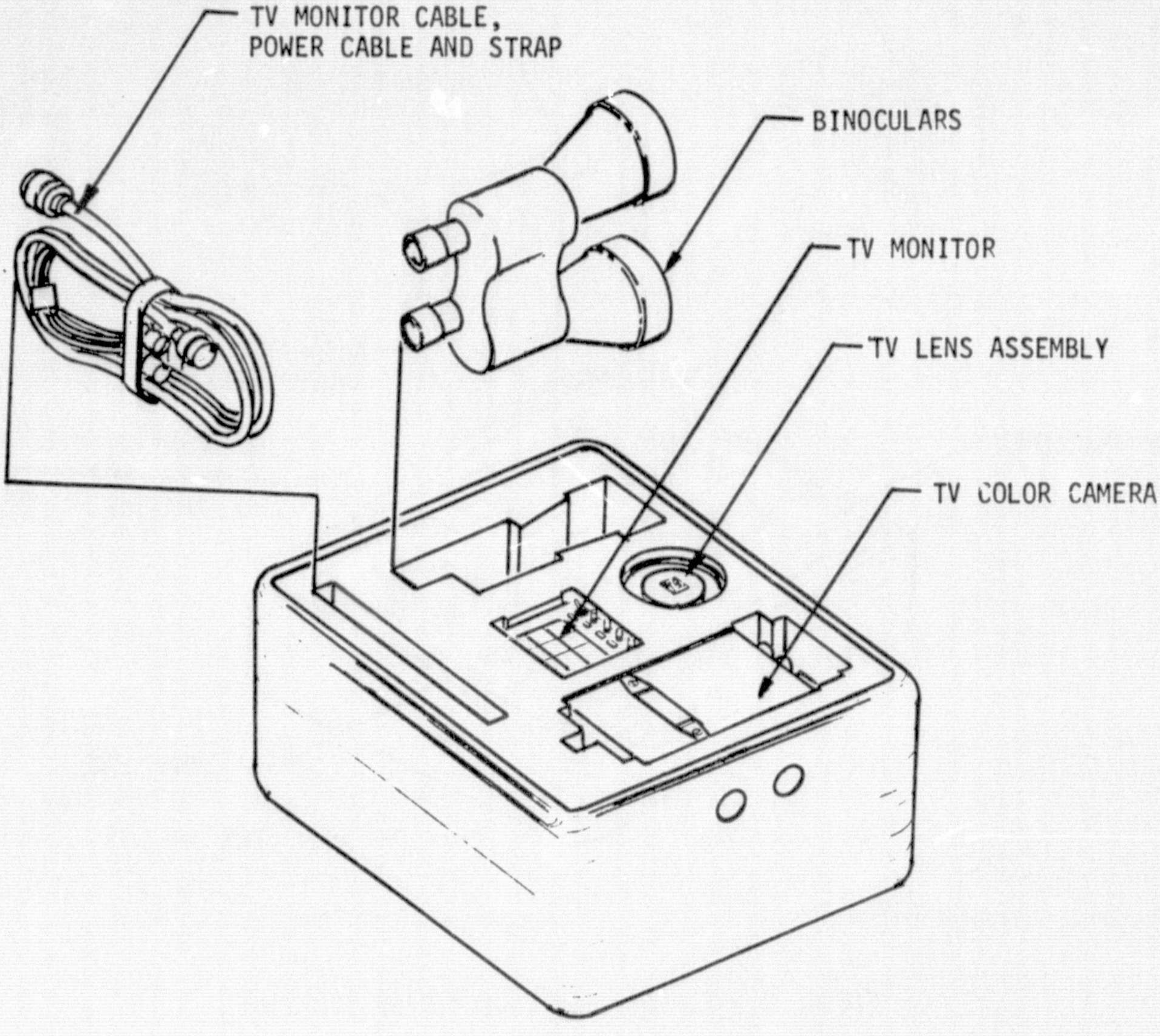


FIGURE 2.9-8: Stowage Locker M74R

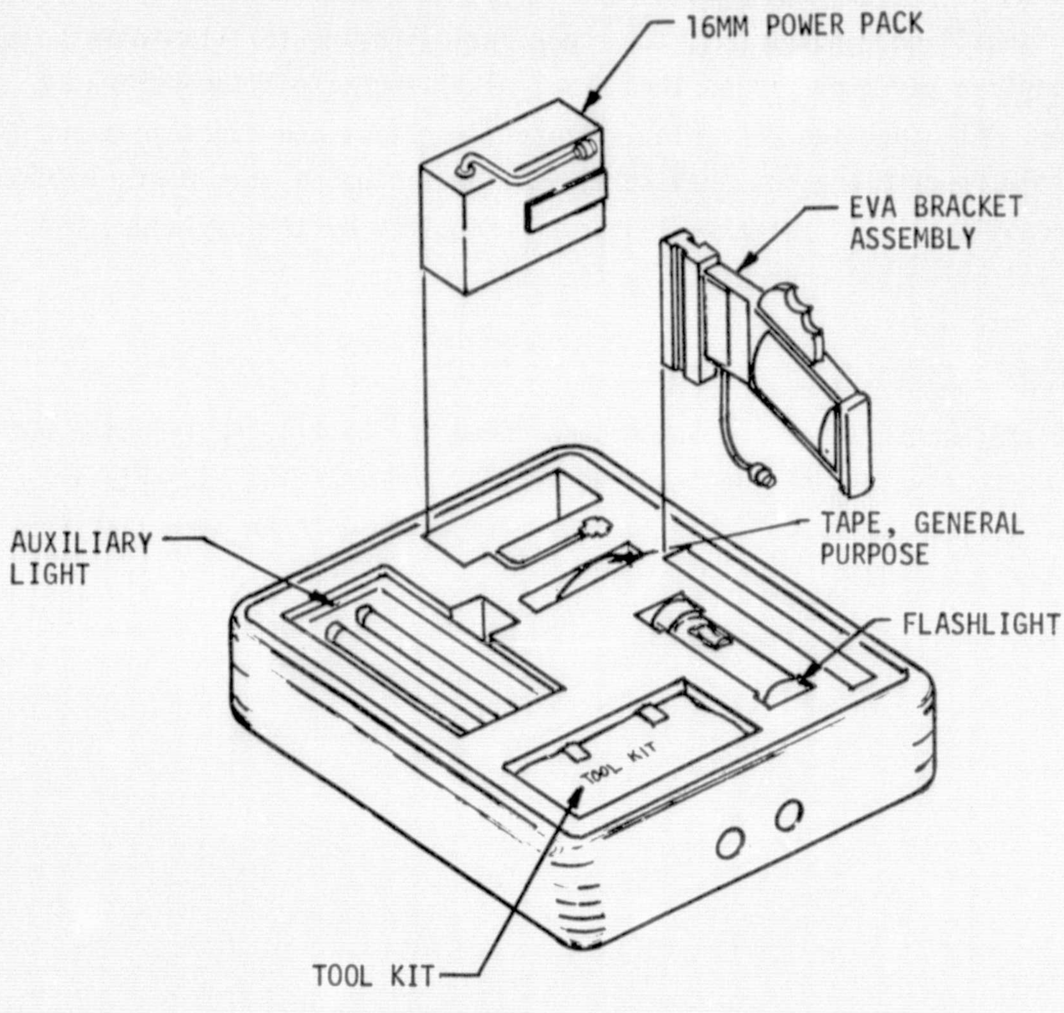


FIGURE 2.9-9: Stowage Locker M74U (Bottom)

2.9.8 Portable Lights

Portable lights are not currently included in the Shuttle baseline EVA system inventory but may be required for certain Orbiter and payload EV operations. Representative payload EVA mission scenarios, developed in Volume II of this report, identified requirements for additional lighting to illuminate areas of the payload bay and both berthed and free-flying satellites during EV servicing. Although the portable light configuration and specifications for the Shuttle Program are not available, it is anticipated that portable units will be developed. If portable lights are required by the payloads, the lights will be weight chargeable to the user.

2.9.9 EVA Portable Workstation

Portable EVA workstations are being considered for Shuttle application but are not currently part of the baseline system. Workstation concepts are presented in Section 2.7 of this report. The units will be weight chargeable to the payloads.

SECTION 2.9 REFERENCES

2.9.1 Crew Station Review No. 12 (Shuttle), Rockwell International Space Division, Contract NAS 9-14000, SSV75-22, 29-31 July 1975.

2.9.2 NASA List of Potential Space Tools and Equipment, Raff Associates, Contract NAS 2-5073, Report No. CR-1760, May 1971.

2.9.3 Shuttle Stowage Installation Drawing, NSD-OV-1021, April 1975.

2.9.4 Shuttle ECLSS and Crew Equipment Payload Penalty for Missions With Larger Crews and Extended Duration, CSD-SH-015B, JSC-06941, April 25, 1975.

2.10 NEW EVA SUBSYSTEM REQUIREMENTS

Nine typical EVA mission scenarios were developed by the study and are contained in Volume II of this final report. The mission scenarios are based on the payload EVA tasks identified in Section 2.0, "EVA Task Selection and Task Completion Plans" (Volume II). The potential EVA tasks were identified from an analysis of four candidate Shuttle payloads as specified by the NASA in the contract Statement Of Work (SOW). In selecting the EVA tasks for developing typical EVA mission scenarios, emphasis was placed on selecting tasks that would have application across numerous candidate payloads.

Upon completion of the EVA mission scenarios, the study has indicated that the Shuttle baseline EVA system, with the addition of payload bay translation aids and EVA workstations, provides adequate support for performing most of the selected payload tasks. Payload bay translation aids (e.g., handrails, handholds, tether points) and portable EVA workstations are currently (early 1976) under study by the NASA Johnson Space Center for inclusion in the baseline EVA system. Only additional carry-on items, such as hand tools, parts retainers, portable handholds, etc., to perform "standard" tasks or enhance EVA operations were identified and recommended as new EVA subsystem requirements. No additional major EVA subsystem requirements were identified. The additional EVA items recommended as Shuttle baseline EVA equipment are listed in Table 3.3.1, "Payload EVA Task Support Requirements Summary", Volume II of this report, page 3.1-4.

SECTION 3.0 EVA OPERATIONAL MODES DESCRIPTION

3.1 INTRODUCTION

The application of EVA to Shuttle payloads encompasses a number of potential operational modes which combine the capabilities of both the EV crewmembers and Orbiter subsystems. The primary EVA operational modes considered applicable to Shuttle payloads and are receiving NASA study are listed below:

- Unaided EVA: conventional mode in which suited EVA crewmembers use handrails, handholds, and passive Orbiter structures to translate to and from a worksite.
- RMS with the Remote Manipulator System (RMS): mode where suited EVA crewmembers use the RMS for cargo transfer to and from the worksite; the crewmembers do not physically interface with the RMS.
- EVA on RMS: mode where a suited EVA crewmember uses the RMS as a "cherry picker" to translate cargo, EVA workstations, tools, etc. to and from the worksite, provide a translation path and position workstations at the worksite.
- EVA with Manned Maneuvering Unit (MMU): mode when suited EVA crewmembers use the MMU for translating cargo and themselves to and from worksites (including worksites outside the payload bay) under external power.

The unaided EVA mode was used during previous U. S. space programs in crewmember translation activities outside the vehicle. The crewmembers normally remained in contact with the vehicle and were tethered during all EV operations. Scientific data packages and EVA supporting hardware were transported either in a hand-carry mode or by employing tubular, extendible members and "Brooklyn" clothesline systems. The Shuttle EVA provisions, RMS, and MMU systems will provide the capability to mutually complement external operations that could not be accomplished independently.

SPACE SHUTTLE EVA

The general allocation of EV payload and Orbiter functions across the Shuttle onboard subsystems are primarily as follows:

- EVA crewman -- performs manipulative and monitoring tasks at required payload, payload bay, Orbiter exterior and free-flying payload worksites.
- RMS -- performs handling of massive payload servicing/refurbishment equipment and cargo; provides EVA translation route to Orbiter-attached payloads and Orbiter vehicle areas; provides EVA crewmember stabilization/restraint (workstation) at worksites, ancillary lighting, and operations video monitoring.
- MMU -- provides autonomous translation capability for EVA crewmembers to sites outside the payload bay [initially limited to 100 m. (330 ft.)], free-flying payload and Orbiter external inspection, Orbiter Thermal Protection System (TPS) repair, scientific data retrieval, cargo transfer and rescue operations.

Since most of the EVA operational modes described are unique to the space program, three of the modes have not been demonstrated on previous space flights. The EVA operational mode performance qualification status in early 1976 is depicted in the following chart. Each mode will be evaluated and qualified using earth based simulation facilities prior to being committed to orbital operations.

EVA OPERATIONAL MODE	PERFORMANCE QUALIFICATION STATUS
Unaided EVA	Demonstrated on pervious space flights -- operational capability
EVA With RMS	Performance assumed based on analytical study results
EVA On RMS	Performance assumed based on analytical study results
EVA With MMU	Demonstrated inside vehicle on previous space flight as Experiment M509 and can be verified by subsystem design similarity

SPACE SHUTTLE EVA

The remaining sections of this document are designed to identify and describe the available modes for accomplishing on-orbit payload servicing functions by utilizing baselined Orbiter systems to support planned and contingency EVA missions.

3.2 UNAIDED EVA

3.2.1 Operational Mode Summary

The unaided EVA crewman operational mode is described as extravehicular functions achieved by the crewman with the assistance of handrails, handholds, tethers, foot restraints and hand tools only. Support systems required to provide a habitable environment for the EVA crewmen (i.e., the Extravehicular Mobility Units) are mandatory for any EVA operations and are considered basic equipment during all EVA operational modes.

Handholds and handrails provide the primary crew translational capability. The EVA handhold/handrail system may be configured either as a single or dual (parallel handrails) system, portable or permanent, and continuous or segmented to meet vehicle structural requirements. Crew stabilization and equipment restraint tethers are used primarily for (1) stabilizing the EVA crewman at a worksite, (2) restraining and temporarily stowing equipment, and (3) securing cargo to the crewman during transfer operations to avoid loss. Foot restraints are used to stabilize and restrain the crewmembers at a worksite and are mandatory for efficiently conducting most EVA missions. Hand tools, as part of the unaided EVA operational mode, consist of a standard complement of household/mechanic's tools (in kit form) carried to the work areas by the EV crewman. EVA operations accomplished with equipment in addition to the hardware identified above are classified as an assisted operational mode and described in a subsequent section.

3.2.2 Unaided EVA Capability

The unaided EVA crewman operational mode was used as the primary method to accomplish EV tasks on previous U. S. space programs. The EVA crewmen employed handrails and handholds on the Gemini Program to access and retrieve experiment packages, assist vehicle docking and evaluate maneuvering unit donning. Tethers were used to restrain the EV crewman, experiment packages and

cameras. Foot restraints were also used to stabilize and restrain the crewman during EVA photographic experiments, maneuvering unit donning and hand tool evaluations. The earth orbiting portion of the Apollo Program was utilized, in part, to evaluate crew translation and cargo transfer capability, body attitude control, and qualify EVA as an operational mode significant to orbital space functions. Apollo trans-earth EVA was used to retrieve panoramic and mapping camera cassettes from the scientific instrument module located on the Command Service Module (CSM), Figure 3.2-1. The largest camera was 49.0 cm. (19.3 in.) in diameter by 15.7 cm. (6.2 in.) wide and weighed 42.3 kg. (85 lbs.)--Ref. 3.2.1.

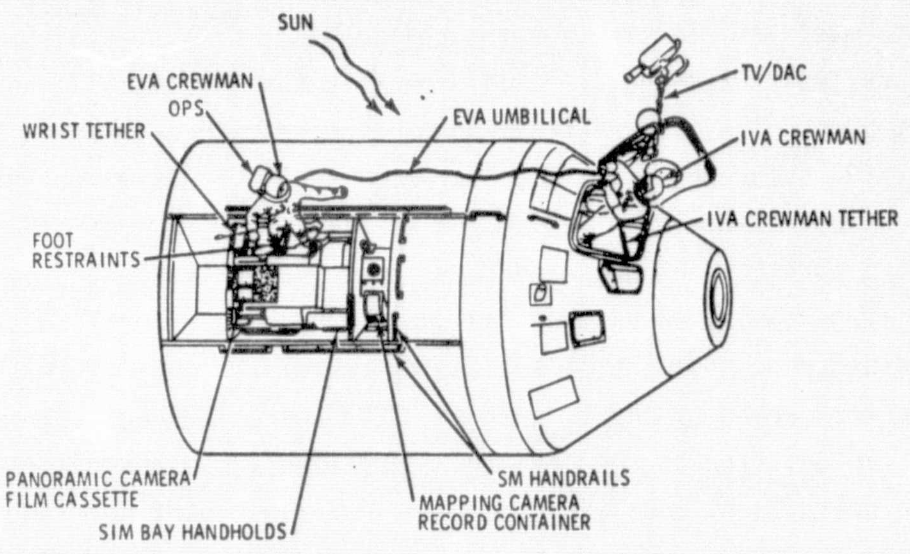


FIGURE 3.2-1: Film Magazine Retrieval During Apollo

SPACE SHUTTLE EVA

The Skylab planned and contingency EVA operations best represent the type and duration of EVA requirements anticipated for the Space Shuttle and payloads. Originally six Skylab EVA's were planned for an expected 29 man-hours outside the vehicle. The planned objectives were to retrieve solar astronomy film data and particle sample collection. However, the loss of a meteoroid shield on the Orbital Workshop (OWS), loss of one OWS solar array panel, and jamming of the remaining array panel resulted in a total of 10 EVA missions. The 10 EVA's extended the EVA time to 82.5 man-hours. During the EVA's, all planned tasks were completed and 18 additional mission objectives, including 13 in-flight repair tasks, were accomplished. The EVA tasks ranged from repairing a film magazine filter wheel using a "standard" screwdriver to erecting a permanent thermal cover over the missing meteoroid shield area. Much of the Skylab salvage work was performed using onboard makeshift implements and modified off-the-shelf tools/equipment delivered on subsequent Skylab flights. The numerous and diverse EVA operations performed on the Skylab Program are summarized in Reference 3.2.2, Skylab Extravehicular Activity. Crewman capability to perform required tasks was a factor only when supporting stabilization, mobility and restraint aids were not provided.

3.2.2.1 Crew Translation/Cargo Transfer Rates

The distance translated and frequency of translation during previous orbital space programs were not major factors relative to crew EVA time allocation. The 18.3 m. (60 ft.) Shuttle Orbiter payload bay and shorter missions (7 days) may, however, require more consideration and planning of EVA crew time including translation rates. Nominal or maximum (i.e., safe) EVA crewman translation rates have not been established for either the unencumbered crewman or crewmen performing cargo transfer functions.

Most EVA documentation addressing translation times indicates EVA translation rates of .21 to >.31 m/sec (.7 to >1.0 fps) for transferring small packages [i.e., <.03 m^3 (<1 ft^3) and <45 kg. (<100 lbs.)] over various vehicle surface geometries using non-continuous handrails. Transfer rates for larger and

more massive cargo ranged from .09 to .21 m/sec (.3 to .7 fps) with package moments of inertia up to 115 kg-m. sec^2 (100,000 in-lb. sec^2).

Transfer rates for an unencumbered spacesuited crewman (i.e., no cargo) over exterior vehicle surfaces and handrail routings must be studied relative to safety, tethering requirements, life support system constraints, transfer volume, time constraints, etc. Under conditions of a straight handrail translation path through the Shuttle Orbiter payload bay, it is generally accepted that crew translation rates in excess of .6 m/sec. (2 fps) can safely be attained. Crew translation velocity in the vicinity of equipment potentially hazardous to the crewman, his support equipment or the vehicle/payloads must be varied to satisfy both mission and safety requirements.

3.2.2.2 Mass Handling--Unaided EVA

Man's capability to maneuver equipment modules, experiments, payloads and rescue systems in the zero-gravity environment, independent of assisting mechanisms, will enhance on-orbit EVA payload servicing. Appropriate crew mobility aids, restraints and the design of the cargo requiring transfer are the key elements in EV equipment handling. The design of EV transportable hardware must consider module size, quantity, configuration, mass, transfer distance, time, temporary stowage, number of EVA crewmen and handhold/grasp location relative to the mass center of gravity.

Upper limits have not been established regarding the size and mass of modules that can safely be handled in zero-g by one crewman independent of assisting mechanisms other than mobility aids. Spacesuited simulations conducted on the KC-135 "zero-g" aircraft with packages of .76 x 1.02 m. (40 x 30 in.) frontal dimensions and mass of 82 kg. (180 lbs.) did not disclose translational, positioning or control problems. In spacesuited water immersion simulations, crewmen have handled 3,856 kg. (8,500 lbs.) Shuttle payload mockups during manned payload deployment evaluations.

The limited on-orbit cargo transfer simulations conducted appear to leave voids in information necessary to formulate baseline cargo transfer guidelines. Most simulation results, however, agree on the following:

- The mass moment of inertia can be the most significant factor in package control during translation and positioning.
- The location of handholds and grasp areas with respect to the package center of gravity is important in the design of on-orbit transferable equipment.
- The package size should not significantly limit crew visibility, particularly during one-man transfer.
- The transfer velocity should be decreased as the package mass increases to ensure safe transporting.
- Factors such as crewman strength, mobility aids, package configuration, etc., affect cargo transfer performance.
- Manned cargo transfer capability exceeds that shown in simulations conducted to date.
- Two-man cargo transfer teams should be employed where large massive equipment may injure the crewman or damage vehicle/payload hardware.

Manned cargo transfer and equipment handling requirements on previous orbital space programs have not approached the EVA crewman's maximum capabilities. Ground based simulations are not sufficiently conclusive at this time to place limitations on the size, mass, and moment of inertia of equipment handled and transported by EVA crewmen. Additional simulations are planned by NASA; however, simulation schedules and release dates of data are not presently available. In the interim, designers of on-orbit transferable hardware should consult previous designs but not be limited by present simulation or previous in-space experience.

3.2.2.3 Suited Task Performance

Suit mobility degradation from the normal shirtsleeve condition is not of sufficient magnitude to directly affect crew force-torque application. An important element when designing equipment or worksites for spacesuited operation is to provide adequate workspace and limb access for the crewman to attain a position which maximizes his force output. The crewman should not be forced to use poor biomechanical body configurations where, in many instances, poor performance may be erroneously attributed to suit or life support system encumbrance. Given a properly designed extravehicular man-machine interface, the most significant factors are access to the interface and proper crewman restraint--not internal "suit torques" or equipment encumbrance on the crewman.

High force application during EVA has formerly been the subject of considerable study by the NASA and various contractors. Although maximum crew force application may be required under certain emergency conditions, the design of equipment to be operated by an EVA crewman is normally much less than the maximum attainable (25% or less) under simulated conditions. Since each EVA interface and hardware operation on previous space vehicles was unique in many respects, detailed specifications, standards, or design requirements were not developed for force and torque applications in EVA. General guidelines, human factors principles, and space flight personnel experience were used. Each EVA task must be studied relative to work piece accessibility, crewman restraints, special tools, etc. Many crewmen with previous flight experience feel that when properly restrained, their general performance capability and maximum force/torque applications in zero-gravity will closely approximate those produced on earth.

3.2.2.4 Manipulative Gloved-Hand Operations

The dexterity of the EVA gloves is a factor in performing fine manipulative tasks. As in earth based industrial applications, tactile proficiency relative to bare-hand operations is degraded and must be considered

in payloads designed for EVA servicing. Most "standard" type handles, knobs, toggle switches, buttons, etc. can effectively be operated with EVA gloves except miniature switches and buttons. Most standard, commercially available hand tools can efficiently be used by EVA crewmen. The standard EVA handhold and handrail cross-sectional configuration (see Subsection 2.6) provides a satisfactory gloved-hand interface for handling and transporting modules.

3.2.3 Limitations--Unaided EVA Mode

Man's capability in the "weightless" orbital environment is enhanced in several operational areas--limited in others. The capability to freely translate and transport cargo within the confines of a spacecraft can be an asset. Conversely, the lack of a gravity field for positioning, stabilization and restraint during extravehicular activities requires a complement of support equipment and confines the unaided EV crewman to exterior areas equipped with mobility aids. Unaided EVA on the Shuttle Orbiter is essentially confined to the payload bay and to berthed payloads. The Shuttle EVA capability can be expanded by addition of the Remote Manipulator System (RMS) and Manned Maneuvering Unit (MMU).

In comparing the unaided EVA operational mode to modes utilizing both man and machine, the major advantages include the following:

- Access to additional external areas of the Orbiter and to free-flying satellites via the RMS and MMU
- Handling massive cargo elements which may exceed unaided EVA capability
- Provide crew translation to and restraint at unprepared worksites.

SECTION 3.2 REFERENCES

3.2.1 NASA: Apollo 15 Mission (AS-510) Post Launch Mission Operation Report No. 1, M-933-71-15, August 1971.

3.2.2 Schultz, D. C., R. R. Kain, and R. S. Millican. Skylab Extravehicular Activity, AAS74-120, paper presented at the American Astronautical Society Twentieth Annual Meeting, Los Angeles, California, August 1974.

3.3 EVA WITH REMOTE MANIPULATOR SYSTEM (RMS)

3.3.1 Operational Mode Summary

The EVA with RMS operational mode is designated as system combinations in which the EVA mission operations are supported by the RMS without a direct man-manipulator interface. (RMS payload support modes in which the EV crewmember and support hardware interface directly with the manipulator arm are addressed in Subsection 3.4.) The manipulator arm configuration is shown in Figure 3.3-1. The general type of RMS functions performed in the EVA with RMS mode will include the following:

- Cargo handling/transport tasks
- Fluid and radioactive material handling
- Extended reach into payload structures
- Inspect and monitor out-of-view payload areas and operations (i.e., beyond EV crewman visual field)
- Provide video coverage of EV payload operations
- Other generic functions defined as payload servicing requirements are solidified.

Under late-1975 RMS design guidelines, the RMS will be operated by one shirtsleeve crewmember from an RMS workstation located inside the Orbiter cabin. The operator will have the capability to direct the control of the manipulator arm throughout all manual and automated operational modes with a direct visual and/or closed circuit television (CCTV) capability. Automatic operation will be employed only when required for precision or speed and to relieve the operator from repetitive and/or tedious tasks. A manual override capability will be provided for all automatic control modes. During EVA with RMS operations, the EV crewmembers will be in audio (and frequent visual) communications with the RMS control station to assist the manipulator operator.

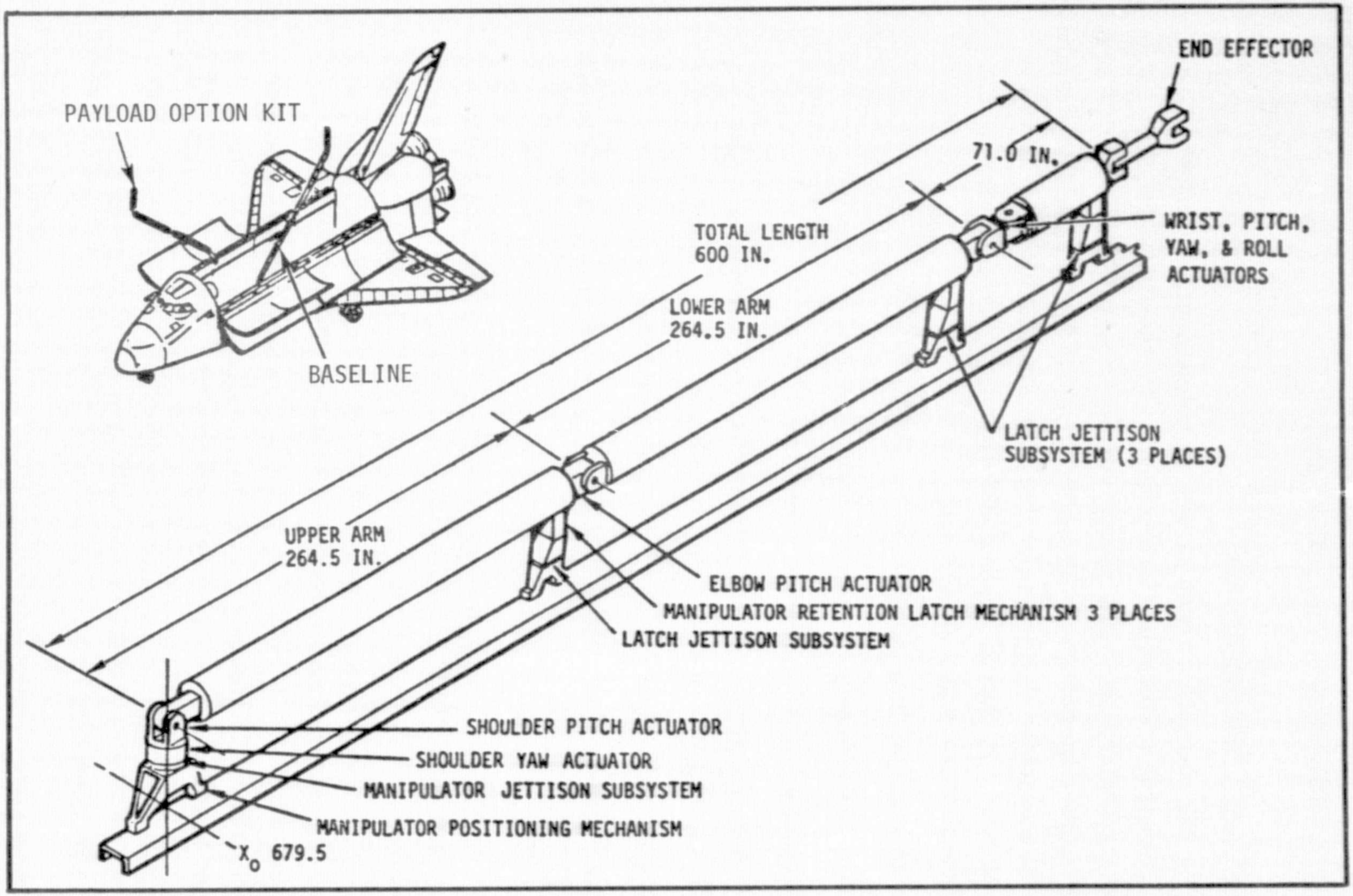


FIGURE 3.3-1: Shuttle Manipulator Arm Configuration

3.3.2 System Capabilities

The basic RMS design charter is to provide the Shuttle user community an attached manipulator system capable of: (1) deploying a 14,530 kg. (32,000 lb.) payload in seven minutes from the payload bay; (2) retrieve and stow a stabilized 11,350 kg. (25,000 lb.) payload in seven minutes; (3) deploy and retrieve a 4.6 m. (15 ft.) diameter by 18.3 m. (60 ft.) long, 29,510 kg. (65,000 lb.) payload; and (4) assist in personnel rescue operations from a stable, disabled Orbiter. The use of Payload Installation Deployment Aids will reduce the RMS payload retrieval and deployment times to approximately 5.5 minutes. Although not a primary NASA design requirement, the RMS is highly applicable in assisting manned EV payload servicing operations. Candidate RMS payload applications are presented in Volume II, Section 2.0 of this report.

Documentation specifying RMS capabilities are distinctly oriented toward payload deployment and retrieval of free-flying satellites. The correlation of manipulator capabilities relative to payload repair, maintenance and servicing must be derived from these distinct RMS design requirements by the payload planners and designers. As a familiarization aid to the RMS capabilities, the following summary is provided. Additional RMS systems description is provided in Subsection 2.3 (Remote Manipulator System) of this document.

3.3.2.1 Payload/Cargo Release Accuracy

Cargo can be released in a gravity-free environment with the following accuracy:

- Attitude error: 15°
- Linear tip-off motion: 6.1 cm/sec (0.2 ft/sec)
- Angular tip-off motion: 0.04°/sec.

3.3.2.2 Payload/Interface Grapple Accuracy (Attach Point Instability)

The payload-to-manipulator attach point must maintain the stability conditions

listed below for free-flight capture by the RMS:

- Attitude rates: ± 0.1 deg/sec
- Attitude hold: ± 7.6 cm. (± 3 in.) maximum motion of interface. (NOTE: During RMS grappling of free-flying payloads, the Orbiter vehicle must maintain stationkeeping with attitude rate not to exceed ± 0.01 deg/sec. Range is TBD.)

3.3.2.3 Fixed Interface Grapple Accuracy (Attach Point Fixed Relative to Orbiter)

The RMS is capable of attaching to fixed payload and Orbiter interfaces or positioning modules/cargo within ± 10.2 cm. (± 4 in.) linear and 15° rotational accuracy. Major factors affecting positioning accuracy are: (1) control system tolerance, (2) visibility, and (3) end effector design.

3.3.2.4 Force Application at End Effector

The manipulator arm can apply a 6.8 kg. (15 lb.) force at the end effector in the fully extended position. Forces in excess of 6.8 kg. (15 lbs.) can be exerted depending on the location and attitude of the manipulator joints and end effector. Figure 3.3-2 depicts force application values at the Orbiter centerline and at various locations referenced from the Orbiter X_o, Y_o, Z_o coordinates. Forces in excess of 23 kg. (50 lbs.) can be applied.

3.3.2.5 Manipulator Arm Tip Velocity (End Effector)

The maximum tip speed for payload and cargo transfer is .61 m/sec (.2 ft/sec) when transporting a 29,510 kg. (65,000 lb.) mass. Since the potential EV payload servicing functions (currently defined) require less massive cargo handling than the total payload weights, tip velocities near the no-load speed should be assumed for payload servicing operations.

3.3.2.6 Manipulator Arm Stopping Distance

A stopping distance of .61 m. (2.0 ft.) is required when transporting a

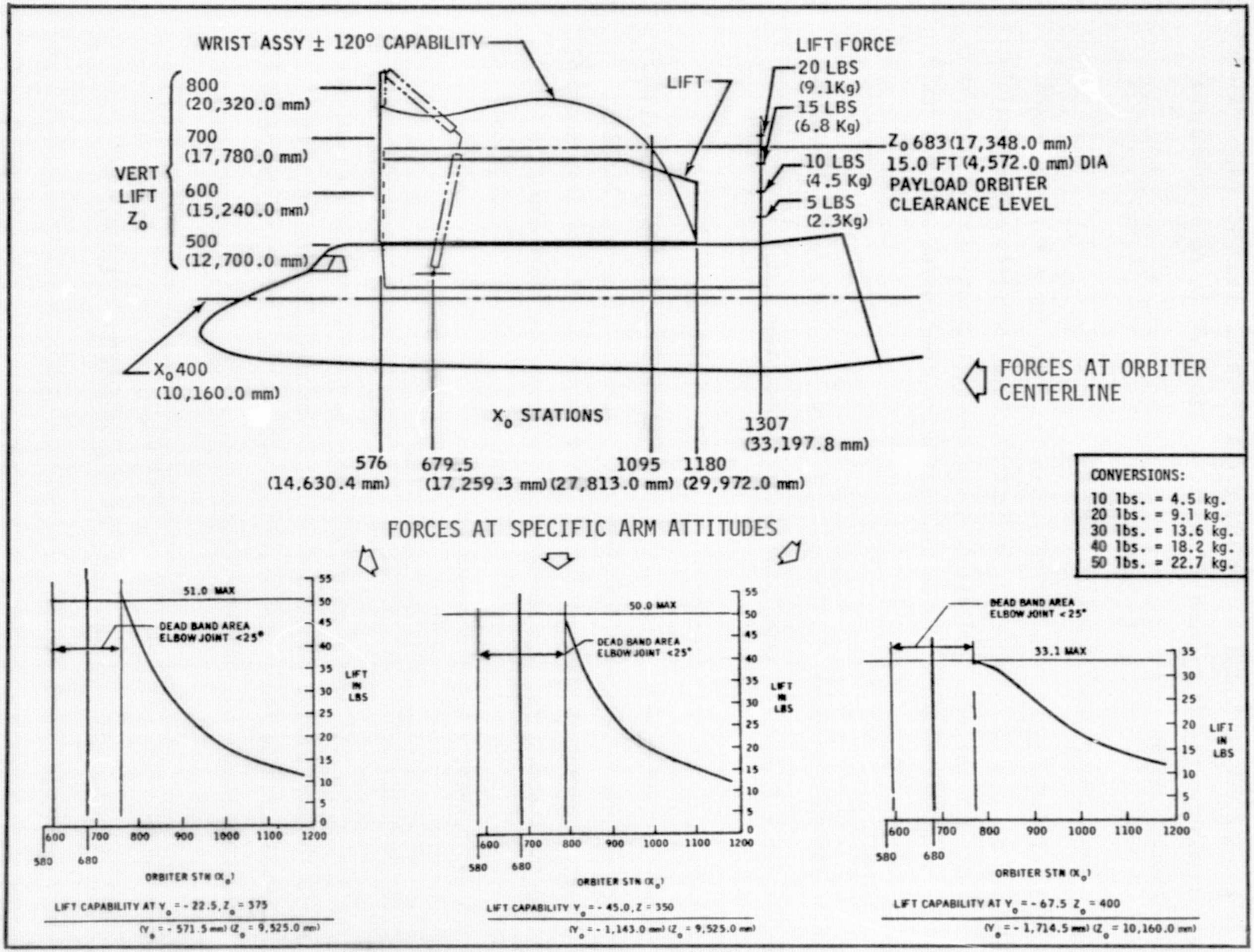


FIGURE 3.3-2: Manipulator Arm Force Capability

14,530 kg. (32,000 lb.) mass at .06 m/sec (.2 ft/sec). Less stopping distance should be assumed for EV payload servicing applications based on the cargo/module masses handled.

3.3.2.7 Manipulator Arm Tip Deflection

The ratio of end effector tip deflection to tip force for a fully-extended arm is .56 cm/kg (.10 in/lb). The deflection characteristics are compatible for EVA with RMS payload applications since tip deflections during acceleration and deceleration periods with the mass being transported are relatively small.

3.3.2.8 Manipulator Reach

(See Section 2.3, Remote Manipulator System, Subsection 2.3.3.)

3.3.2.9 Manipulator End Effector

A standard end effector will be provided for all payload handling operations with a capability to exchange end effectors on-orbit. A payload handling end effector concept is shown in Figure 2.3-6 in Section 2.3 of this document. End effector concepts for payload servicing consideration are shown in Figure 3.3-3. It should be noted that Figure 3.3-3 depicts concepts only and all are not currently being developed by NASA.

3.3.2.10 Payload Mechanical Interface

The payload mechanical attach point will be a passive interface and nonfunctional in the performance of RMS operations. The end effector and wrist assembly will provide the active elements for coupling, securing and manipulative functions at the payload interface.

3.3.2.11 Manipulator Lighting and TV Viewing

(See Section 2.3, Remote Manipulator System, Subsection 2.3.3.4.)

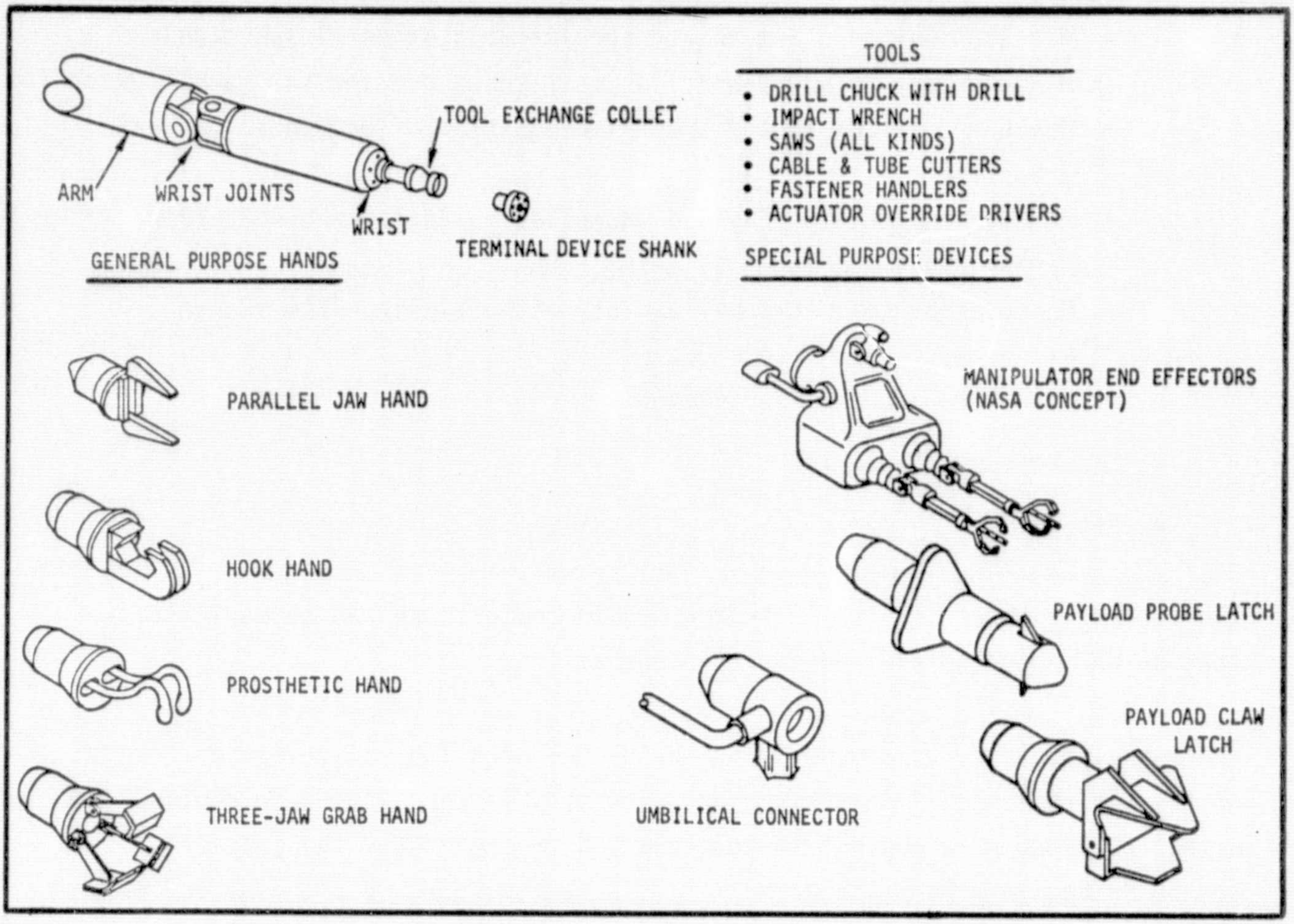


FIGURE 3.3-3: RMS End Effectors (Concepts Only)

3.3.2.12 RMS Operating Modes

Three modes are available for RMS operation: automatic, manual, and manual direct modes. The automatic mode allows computer-programmed arm movements, without manual interface, to perform the following payload deployment and retrieval functions:

- Unstow arm
- Deploy arm

- Maneuver routine
  - Maneuver unloaded arm to any specified position (inspection)
  - Maneuver arm to any specified position to prepare for manual grappling
  - Maneuver payload to any specified position after manual payload grappling
  - Maneuver payload to Payload Installation Deployment Aids (PIDA)
  - Maneuver payload into bay using PIDA
  - Maneuver payload into payload bay without using PIDA (large allowable clearances)
  - Return to pre-deploy position
- Secure arm
- Stow arm.

The automatic mode can also be programmed to perform payload servicing tasks that do not require fine manipulative operations.

The manual mode allows arm movements using the hand controller system located at the Orbiter cabin RMS workstation. The manual mode is used in conjunction with a resolved rate control system in which the motion of the end effector can be driven in a rectilinear motion at a rate proportional to the deflection of the translational hand controller, and likewise a rotational rate proportional to the deflection of a rotational hand controller. The resolved rate technique relates translational and rotational commands of the end effector reference system to the manipulator arm joint angle rates in a manner in which the command motion of the reference system is obtained. The following payload deployment and retrieval functions can be accomplished in the manual mode:

- Unstow arm
- Deploy arm
- Movement of the unloaded arm using resolved rate
- Grapple of payload
- Movement of the loaded arm using resolved rate

- Insertion of payload into PIDA
- Movement of the payload into the bay using the PIDA
- Movement of the payload into the bay without the use of the PIDA
- Secure arm
- Stow arm.

The manual operating mode will be the prime mode for payload servicing operations.

The manual direct mode allows movement of the manipulator arm on a joint-by-joint basis completely bypassing the computer system. Use of this mode is included in the event of computer failure to stop manipulator arm action and return the arm to the pre-deployed position.

3.3.2.13 EVA Rescue Support

The RMS is designed to support personnel rescue operations from a stable, disabled Orbiter when the crewmembers are equipped with space suits or Personnel Rescue Systems (PRS's) designed for the Shuttle Program. Mobility aids (e.g., handrails, handholds) will be provided on the manipulator arm for EV crew translation. Provisions for attaching portable EVA workstations and for handling large massive equipment modules for EVA support are also being considered in the initial RMS design.

3.3.3 Performance Qualification

The general performance characteristics of the RMS are summarized in Section 2.3.2 (RMS Basic Design Functions) of this document. The RMS characteristics were derived analytically by NASA based primarily on design requirements to deploy and retrieve representative payloads on orbit and assist in personnel rescue from a stable, disabled Orbiter. Preliminary ground-based (earth gravity) simulation programs were also conducted using part-task mockups and a CAM 1400 manipulator system to assist in identifying the RMS design/

performance requirements. The basic CAM 1400 manipulator system was manufactured by the General Electric Corporation and consisted primarily of a 9.2 m. (30 ft.) manipulator arm, electromechanical control subsystems, video TV equipment, computer interfaces, various end effectors, and unique support hardware as required. The simulations were also supported by part-task mockups of the Orbiter payload bay, payload end effector interfaces, and full size 4.6 m. (15 ft.) diameter neutrally buoyant soft payload mockups.

Since remote manipulator systems with the proposed capability, magnitude and complexity have not flown on previous U. S. space programs, systems performance qualifications are currently (late-1975) based on analytical studies and limited simulations. Operational ground-based RMS simulation facilities will be available in early 1977.

3.3.4 Systems Limitations

The application of the Shuttle Orbiter RMS is limited for certain task categories when the system is applied to candidate EVA payload and Orbiter exterior functions. The major limitations based on analyses of representative planned and potential EVA payload servicing applications are:

- Low force capability at end effector
- Low manipulator arm velocity (manipulator joints and end effector)
- Limited end effector positioning accuracy (linear, rotational)
- Restricted reach envelope with berthed payloads
- End effector physical size (payload interface requirements)
- Manipulator arm deflection rate at end effector.

The RMS capability limitations identified above, as applied to payload EVA servicing, are most prominent when handling, transporting, and positioning replacement modules during Orbiter berthed payload servicing operations. Coupling the end effector to the replacement modules/equipment may require removeable interface fixtures due to end effector physical size and configuration if the baseline end effector concept is used. The in-route and

positioning time required in manipulator arm operation can be a factor in multiple-task EVA operations when considering a 6-hour (maximum) EVA capability. Due to RMS end effector positioning accuracy, EV crewmember assistance may be necessary to expedite multiple cargo handling requirements. Manipulator arm access to payloads berthed perpendicular to the Orbiter payload bay is restricted (Figure 3.3-4) particularly when the payload diameter approaches

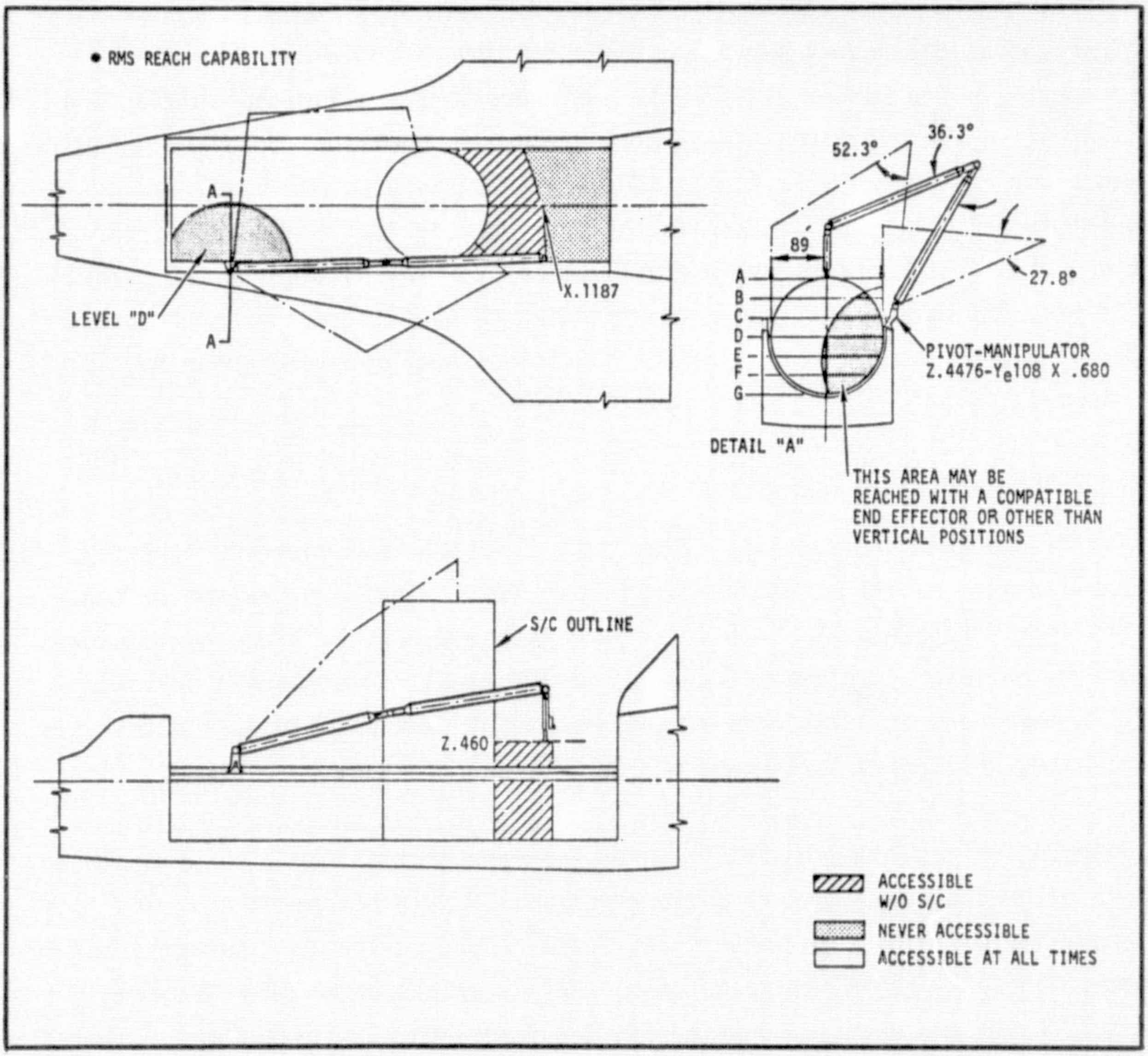


FIGURE 3.3-4: RMS Reach With Payload Installed Vertically

4.6 m. (15 ft.) and 10.7 m. (35 ft.) in length. Provisions for rotating the berthed payloads to access exterior surfaces may be required. The limited force capability at the end effector may also require special payload mechanical interface designs (e.g., connects, disconnects, torque requirements) to accommodate the manipulator systems.

3.3.5 General Operational Concepts and Techniques

Several general EVA with RMS operational concepts applicable to a wide range of potential payload EV servicing tasks are described in the following paragraphs. The number of EVA with RMS operations are limited only by the imaginative and creative faculty of individuals cognizant of payload requirements and EVA-RMS capabilities. However, this study was not designed to identify all EVA with RMS application possibilities but to describe representative applications across the payload community. In addition to the general EVA with RMS operational concepts presented in this subsection, concepts and techniques for specific payload EVA servicing operations are contained in Volume II, Section 2.0 of this report.

3.3.5.1 Cargo Handling

A major RMS role in assisting EV operations is the transporting, handling, and stabilization of large massive cargo items for payload and Orbiter systems servicing. Figure 3.3-5 illustrates the RMS transporting experiment modules between payload bay stowage locations and worksites on a berthed payload. EVA crewmembers are stationed at the stowage and worksite locations to assist latching, unlatching, securing, monitoring, and checkout operations.

Manipulative tasks beyond the RMS baseline capabilities may also be accomplished with alignment assistance from the EVA crew. Module placement and alignment capability would be significantly enhanced at the payload or stowage interface. This RMS assist operation would entail an EVA crewmember grasping the module/cargo and manually positioning the cargo and manipulator arm. A force of 4.5 kg. (10 lbs.) will deflect the manipulator arm 2.5 cm. (1 in.) when the arm is in an extended attitude.

3.3.5.2 External (EVA) RMS Control

Considering the intricate payload tasks involved, cargo mass, manipulator arm, video coverage, time constraints, and payload arrangement/density, a portable RMS control panel would be advantageous in numerous EVA payload servicing operations. A concept is depicted in Figure 3.3-6 in which an EVA crewmember is remotely operating a manipulator arm to transport and handle large payload replacement modules. The arrangement of payloads and experiment hardware in the Orbiter payload bay may obscure direct and TV camera visibility, thereby prohibiting RMS operations from the cabin Payload Specialist Station (PSS). The EVA crewman equipped with a portable RMS control panel would operate the manipulator arm in the obscured areas and assist end effector alignment, module release and hardware securing at the worksite. The portable control panel would consist only of hand controllers and electromechanical subsystems

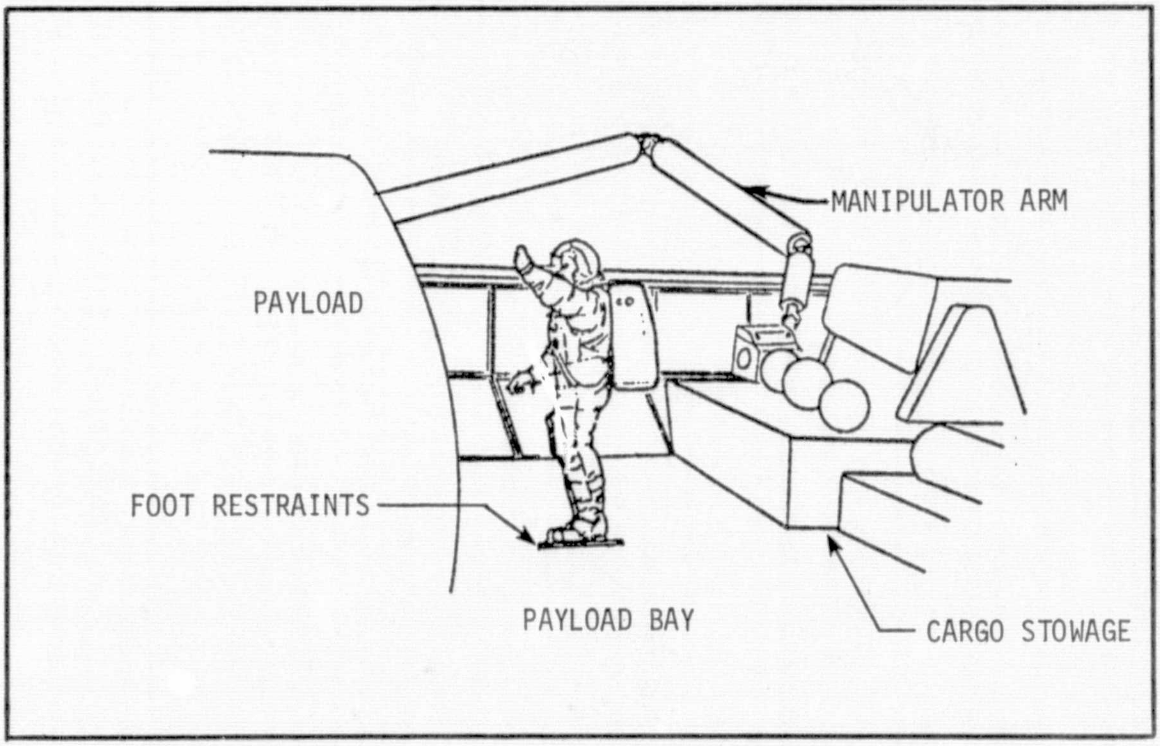


FIGURE 3.3-5: RMS Transporting Cargo Modules (Conceptual)

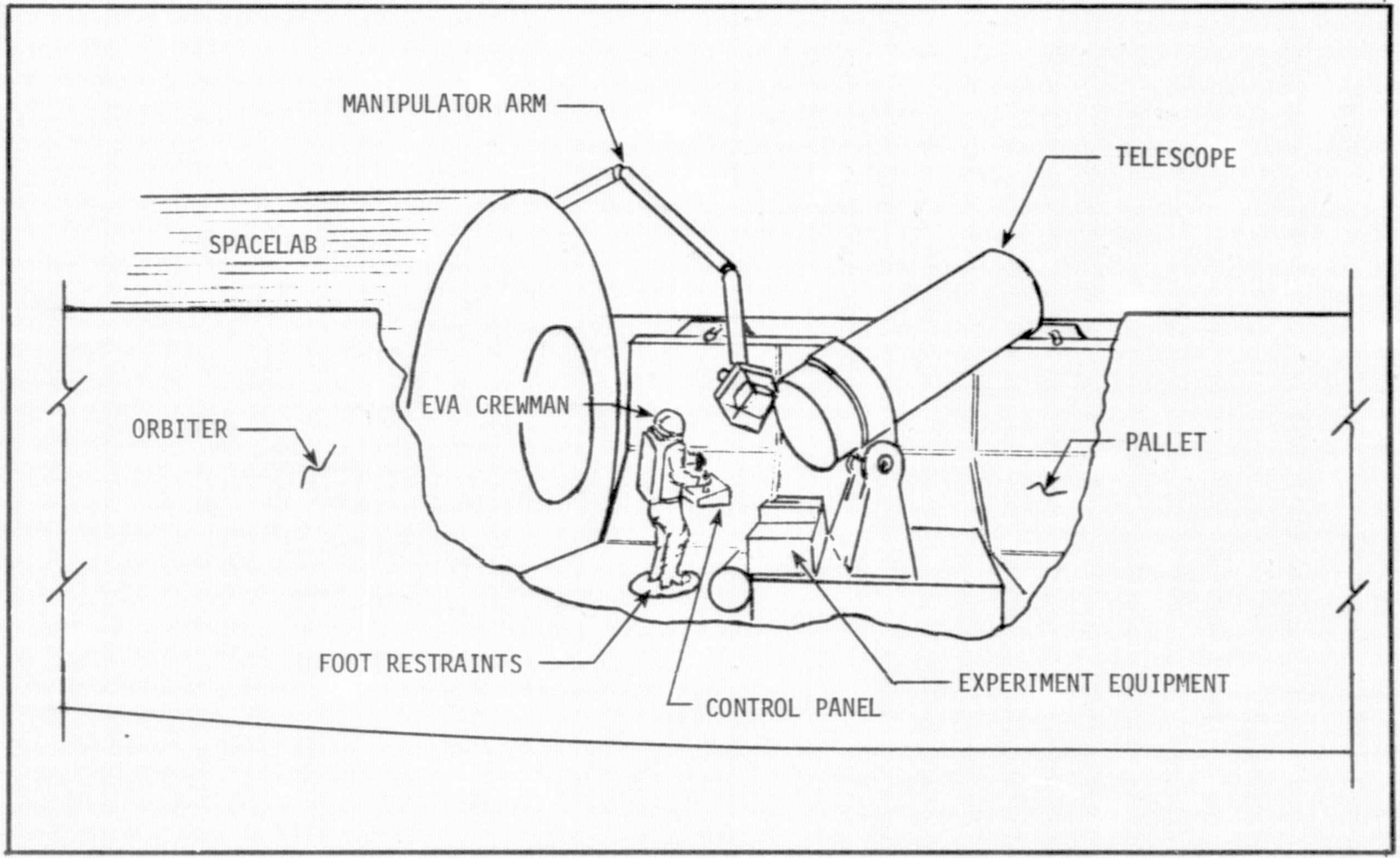


FIGURE 3.3-6: EVA Crewman Remotely Controlling RMS (Conceptual)

mandatory for RMS remote operations. Input signals would be transmitted via hardline to the master control system at the PSS. Manipulator arm operating assistance would be provided to the EVA crewman from the cabin RMS control panel for tasks outside the EVA crewman's field of view.

3.3.5.3 Reach, Lighting, and Video Support

The 15.2 m. (50 ft.) manipulator arm will provide the capability to reach into payload areas inaccessible by the EVA crewman. Access to equipment located within payload structural areas that were not originally designed for EVA servicing may be necessary in the event of payload malfunction or loose equipment.

Application of the RMS in the reach assist mode may be necessary due to payload design requirements or Orbiter bay interface constraints. However, employing the arm following a payload or Orbiter malfunction or an assumed--but unqualified--(real time) failure may enhance mission success or prevent mission abort. Typical applications may include the following:

- Retrieve loose equipment freed as a result of launch vibration
- Inspect payload attachment fittings and structural points for reentry
- Replace electrical, mechanical, hydraulic, pneumatic, etc. connectors/ components
- Assess payload systems for operation/reentry status.

The RMS may also provide a versatile "third arm" for assisting the EVA crew in inspection, monitoring and payload servicing tasks. The manipulator arm TV viewing light can provide auxiliary illumination at EVA worksites, contingency translation paths, and within structural areas without impeding the EV crew. Data acquisition during EVA payload servicing, particularly refurbishment and monitoring tasks, can be provided by the manipulator arm TV camera (Figure 3.3-7). The RMS video system could provide valuable real-time feedback information to ground installations during EVA payload repair. Conversely, payload repair operations could be directed from ground control centers.

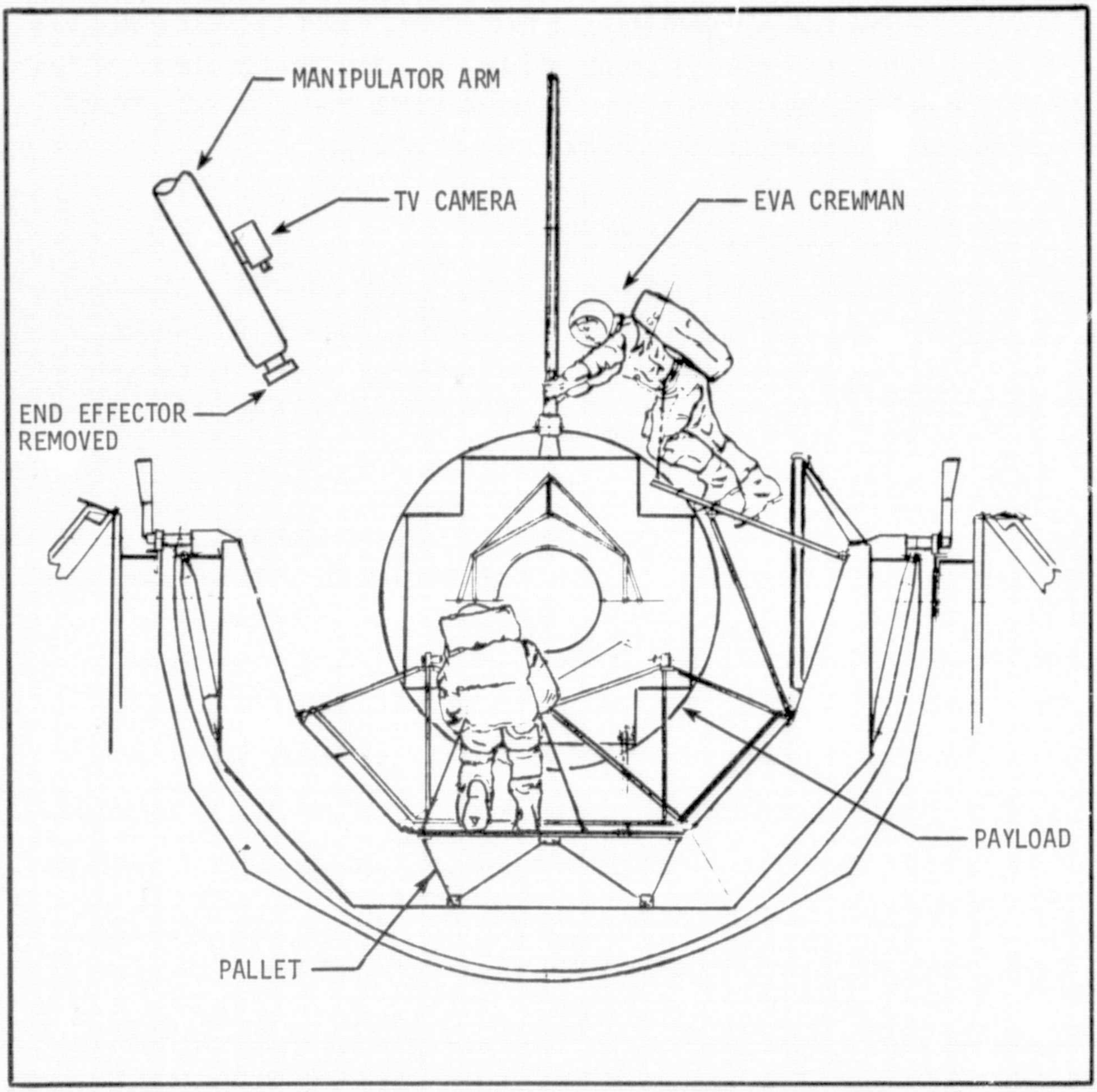


FIGURE 3.3-7: RMS Payload Servicing Data Acquisition

3.4 EVA ON REMOTE MANIPULATOR SYSTEM (RMS)

3.4.1 Operational Mode Summary

The EVA on RMS operational mode is characterized when Orbiter and payload external tasks are performed through directly interfacing EVA crewmembers with the RMS manipulator arm. The EVA on RMS operational mode utilizes the RMS in a quasi-"cherry picker" capacity to provide a crew translation path to EV worksites, directly support EV worksite operations, and provide a workstation for EVA functions. The term "cherry picker" for purposes of this document does not involve a man-rated boom for transporting EV personnel during EVA operations. The crewmembers do not ride the manipulator arm nor "drive" it from an arm-mounted control station. Such applications may be considered in future Shuttle/payload programs but are not addressed in this document.

The EVA on RMS mode provides: (1) translation aids (i.e., handrails, handholds, tether points) on the manipulator arm to permit the EVA crewmembers to access various work areas; (2) provisions for attaching EV workstations and restraints to the arm for worksite access and crew stabilization; and (3) cargo transport and temporary stowage in support of worksite operations. In the EVA on RMS mode, the manipulator arm or end effector is required to be attached at the worksite for arm stabilization during crewman translation and worksite operations.

Equipment such as handrails and EVA workstations, which are major components used in the EVA on RMS operational mode, are discussed below. However, although such component concepts have been studied by the NASA and several working mockups developed, they are not currently (early 1976) baselined for Shuttle applications.

3.4.2 System Capabilities

The Shuttle Remote Manipulator System, Figure 3.4-1, was described in Section 2.3 and the general RMS capabilities presented in the preceding section

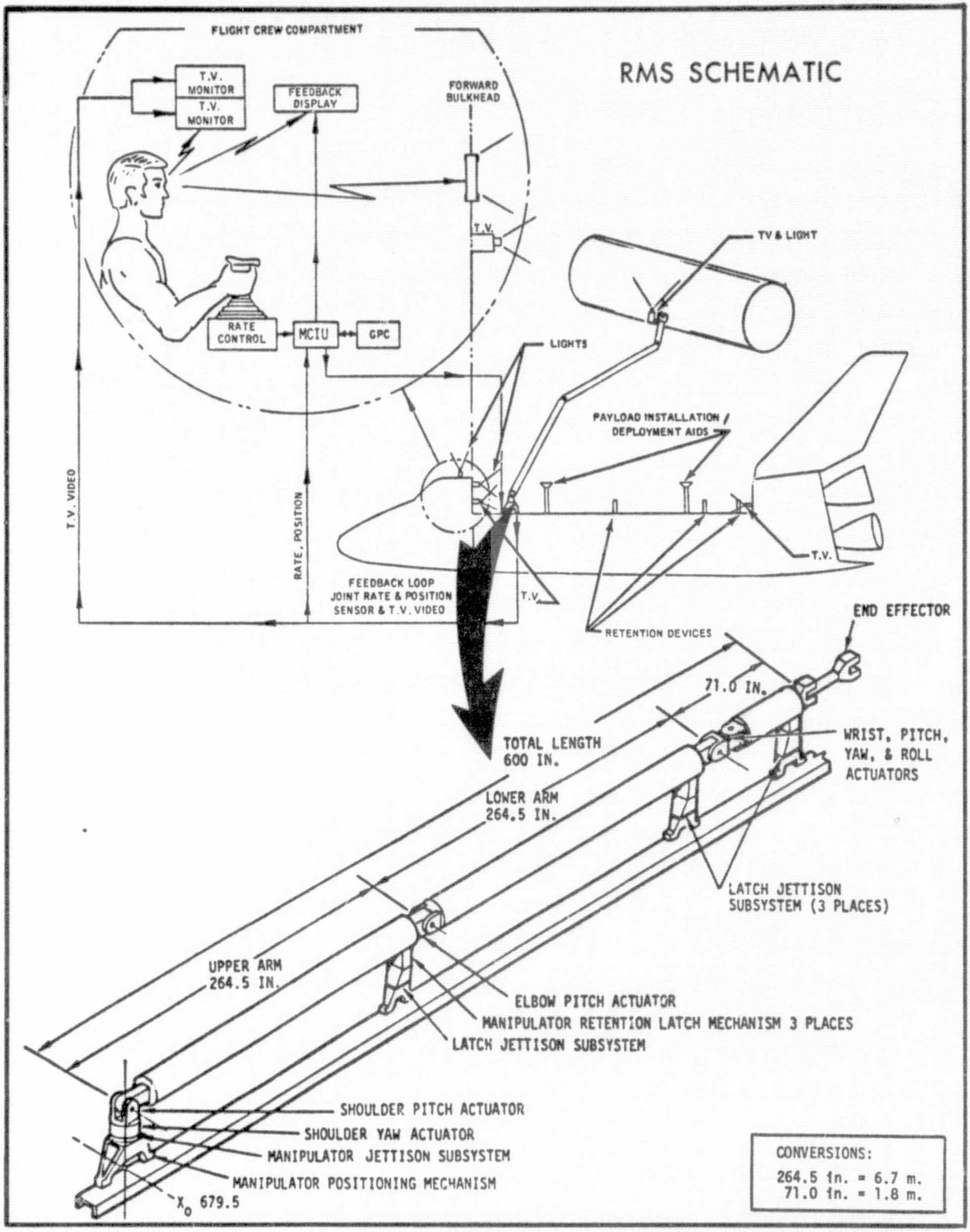


FIGURE 3.4-1: Shuttle Remote Manipulator System

(Section 3.3) of this report. The RMS basic capabilities will remain the same independent of the EVA-RMS operational mode. However, the addition of EV support items to the RMS increases the applications range of both systems. The addition of translation aids and tether attach points to the manipulator arm provides the EV crewmen a translation route and mobility aids for accessing numerous Orbiter and payload areas. The addition of handholds on the manipulator arm wrist assembly or end effector could enhance timely manipulator attachment to interfaces (e.g., payloads, cargo, worksites) by using the EV crewman to aid alignment and final attachment.

Provisions for attaching EVA portable workstations to the RMS wrist assembly or the end effector to portable workstations would provide numerous worksites for payload servicing and repair. The employment of the manipulator arm to transport, position, retain and stow a complement of tools, replacement modules, payload servicing fixtures and equipment at the worksites (accessible from the EVA workstation) would augment payload worksite operations.

3.4.3 Operational Concepts and Techniques

3.4.3.1 Manipulator Arm EV Mobility Aids

The incorporation of crewman mobility aids on the RMS manipulator arm will provide a translation path to all areas within the RMS reach envelope. Assuming a cylindrical manipulator arm configuration, handrails installed the length of the arm (Figure 3.4-2) would provide the capability for crew access and manual cargo transport to Orbiter and payload areas. Handrail installation may vary depending on the arm diameter and stowage volume availability. The maximum arm diameter is limited to 38.1 cm. (15 in.) for Orbiter stowage. Handrail installation may vary from a fixed configuration to a completely retractable design. Conceptual designs are being studied by the NASA and RMS contractor.

3.4.3.2 End Effector EV Positioning Aids

The limited fine alignment capability of the RMS end effector for grappling

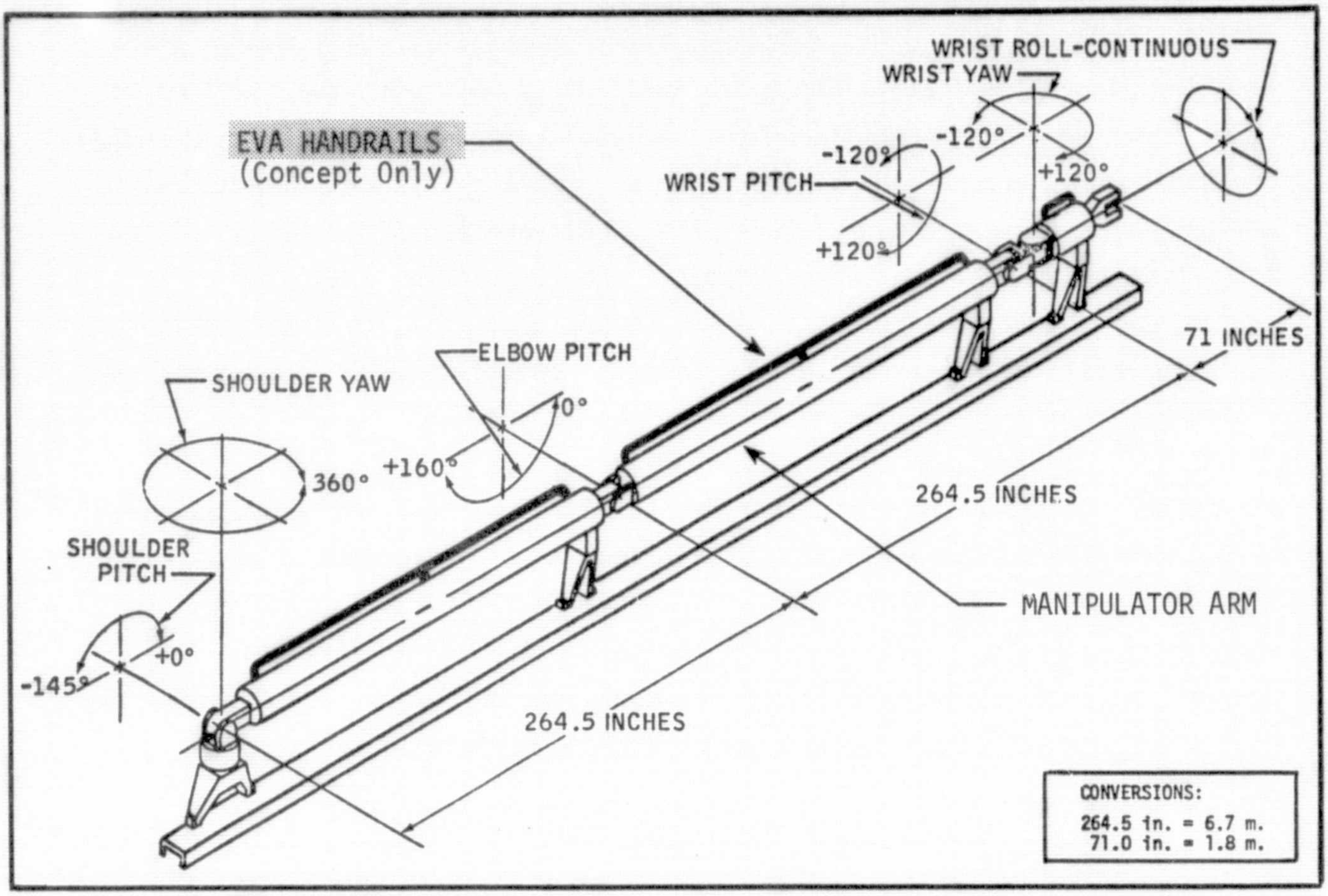


FIGURE 3.4-2: EVA Handrails Mounted on Manipulator Arm (Concept Only)

or connecting to various interfaces may be improved by using the EVA crew-members to assist alignment and final securing/locking operations. The addition of fixed handholds or interface provisions for portable handholds on the manipulator wrist assembly or end effector would allow crewmen assistance, Figure 3.4-3. Depending on end effector designs, handholds or grasp surfaces may be incorporated into the initial design. Handhold inter-face provisions may be incorporated into the wrist assembly or end effector to install Skylab-type IVA portable handholds.

3.4.3.3 Manipulator Arm EVA Workstation

Provisions for attaching portable EVA workstations to the manipulator wrist

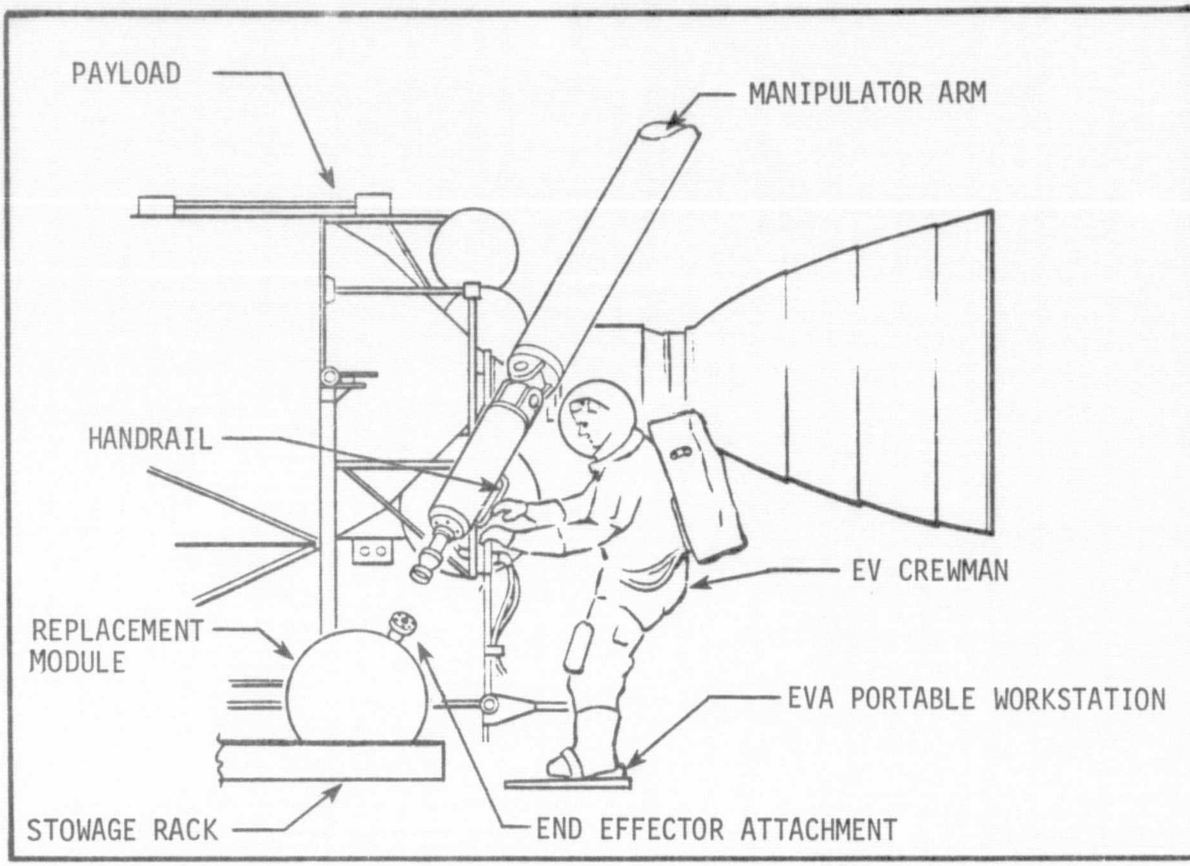


FIGURE 3.4-3: EV Crewman Assisting Manipulator Arm Alignment

assembly or grasping the workstation with the end effector would provide EV crewmen access to various Orbiter and payload areas and restraint for worksite operations, Figure 3.4-4. In concept, the EV crewmember installs the workstation on the manipulator, the RMS positions the workstation, and the crewman accesses the workstation via the manipulator arm mobility aids. Under current design guidelines, the manipulator end effector must be attached at the worksite for stability prior to crewman translation or workstation ingress. A connecting interface will be required at each worksite. The mating interface would be incorporated into either the EVA workstation or manipulator end effector. An electromagnet end effector may be applicable for workstation-to-payload stabilization when a ferrous interface is available.

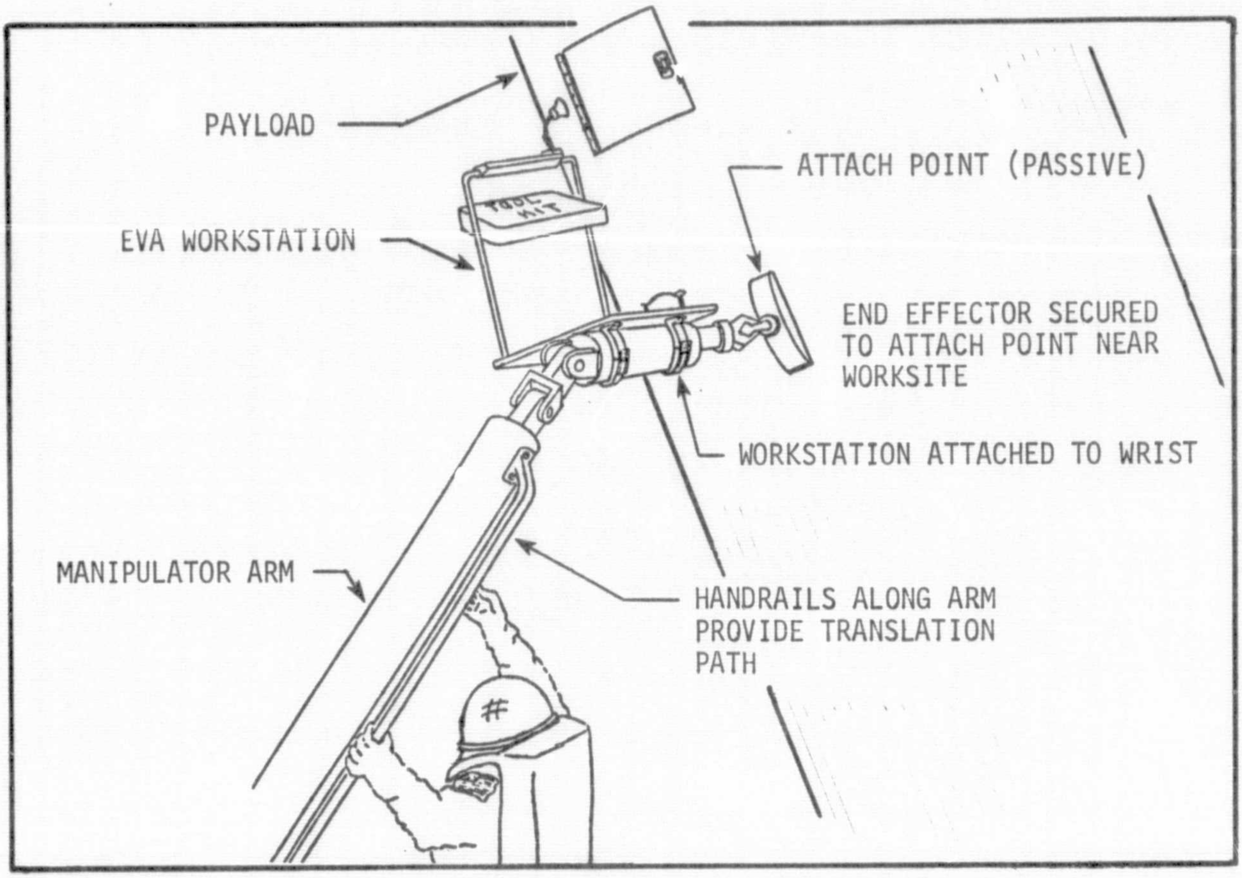


FIGURE 3.4-4: EV Workstation Attached to Manipulator Arm (Concept Only)

Deployable crew ingress aids are provided on each EVA portable workstation and Skylab-type foot restraints for crew stabilization. EVA workstation concepts that attach directly to the worksite to free the manipulator arm for further EVA assistance are being considered.

3.4.3.4 RMS Worksite Support

The RMS direct support role during Shuttle extravehicular activities may include the following:

- Position, display and provide crew access to tools and fixtures at worksites
- Provide transport for payload replacement modules/cargo
- Provide temporary stowage at the worksite for payload components

- Provide a mobile crew and equipment tether
- Stabilize payload components or small payloads for EVA repair (Figure 3.4-5)

The broad application concepts listed for the EVA on RMS worksite support mode can be expanded and specific applications detailed on requirements of individual payloads and their locations/attitudes in the payload bay.

3.4.4 System Limitations

The major RMS capability limitations relative to EVA payload applications were addressed in Section 3.3.4. These design limitations also apply to the EVA on RMS operational mode. In addition, the present design baseline requiring the manipulator arm end effector to be attached at the EV work-site during translation and worksite activities will restrict RMS versatility for EVA support. Two manipulator arms may be required or economically advantageous for specific payload applications.

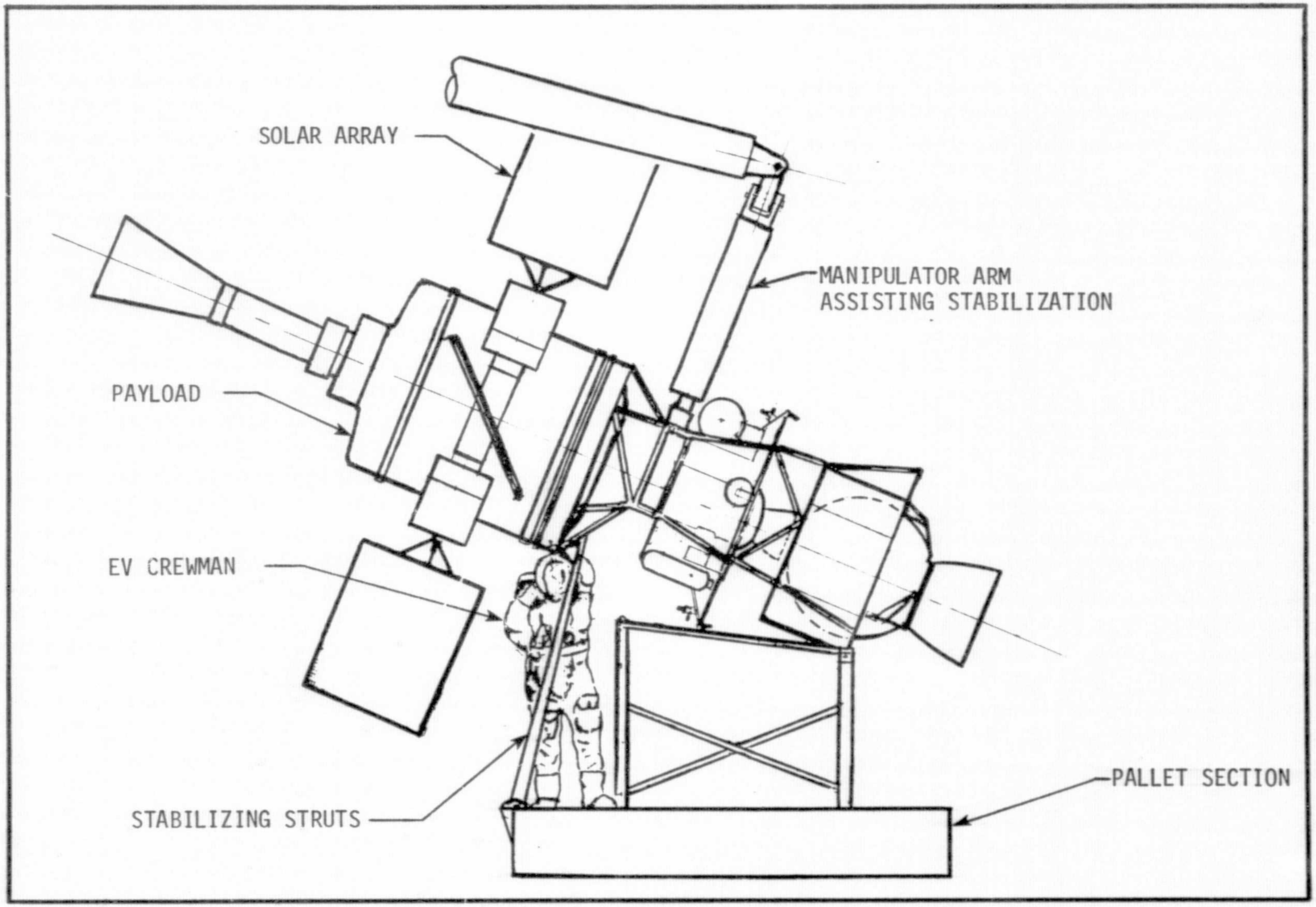


FIGURE 3.4-5: Manipulator Arm Assisting Payload Stabilization

3.5 EVA WITH MANNED MANEUVERING UNIT (MMU) OPERATIONAL MODE

3.5.1 Operational Mode Summary

The Shuttle EVA with MMU operational mode is identified as extravehicular operations performed by crewmen with the assistance of Manned Maneuvering Units for crew transportation, including access to points outside the Orbiter payload bay. The MMU in conjunction with the Shuttle Extravehicular Mobility Unit (EMU), Figure 3.5-1, provides a completely autonomous system for performing EV tasks remote from the primary spacecraft.

The MMU consists of a cold gas nitrogen propulsion system, batteries, power conditioning, control electronics, gyroscopes, hand controllers, and controls and displays to perform required EV functions. The rotational and translational hand controllers--actuated by the right and left hands, respectively--provide six degree-of-freedom control authority. The MMU is described in Section 2.8 of this report.

The MMU is designed for fail-safe EVA operation in which any single hardware failure will not preclude the ability of the crewman to return, untethered and unassisted, to the Orbiter. The MMU incorporates two separate, completely isolated systems in an electrical, propulsion and control logic capability. Both systems used together comprise the prime operating system, and either system can provide a backup capability. The EVA with MMU operational mode can support 6.5 hour extravehicular missions between required MMU and EMU expendables replacement and component servicing (Ref. 3.5.1).

The MMU will normally be stored in the Orbiter payload bay and secured in an MMU flight support station, Figure 3.5-2. The flight support station facilitates the MMU stowage, servicing and don/doff activities. The flight support station provides the capability for one unassisted, EMU suited crew-member to don, doff and service the MMU on-orbit, Figure 3.5-3. MMU servicing functions involve recharge of the cold gas propellant tankage and/or changeout of the batteries (Figure 3.5-4).

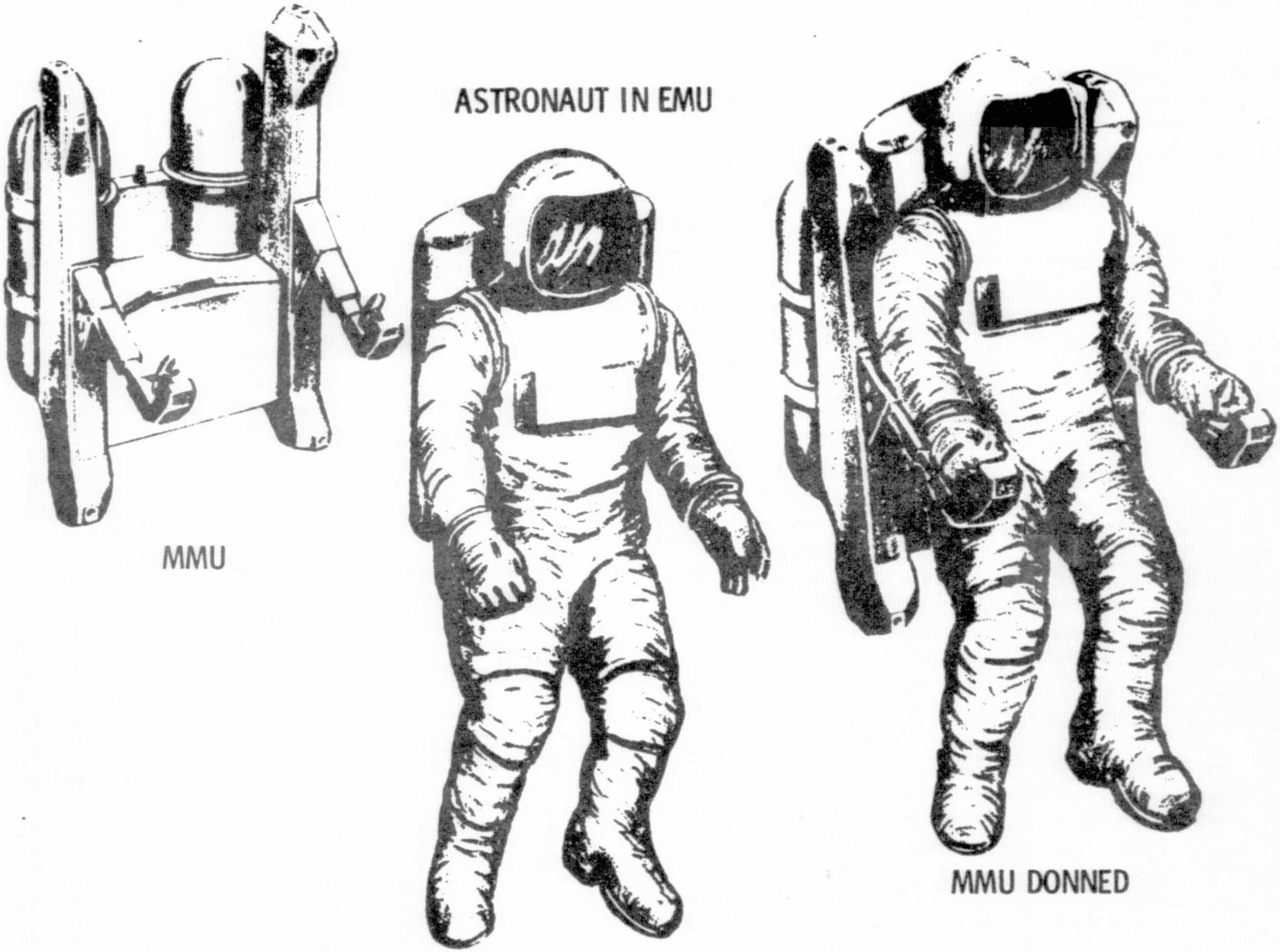


FIGURE 3.5-1: Shuttle Manned Maneuvering Unit (MMU) Conceptual Configuration

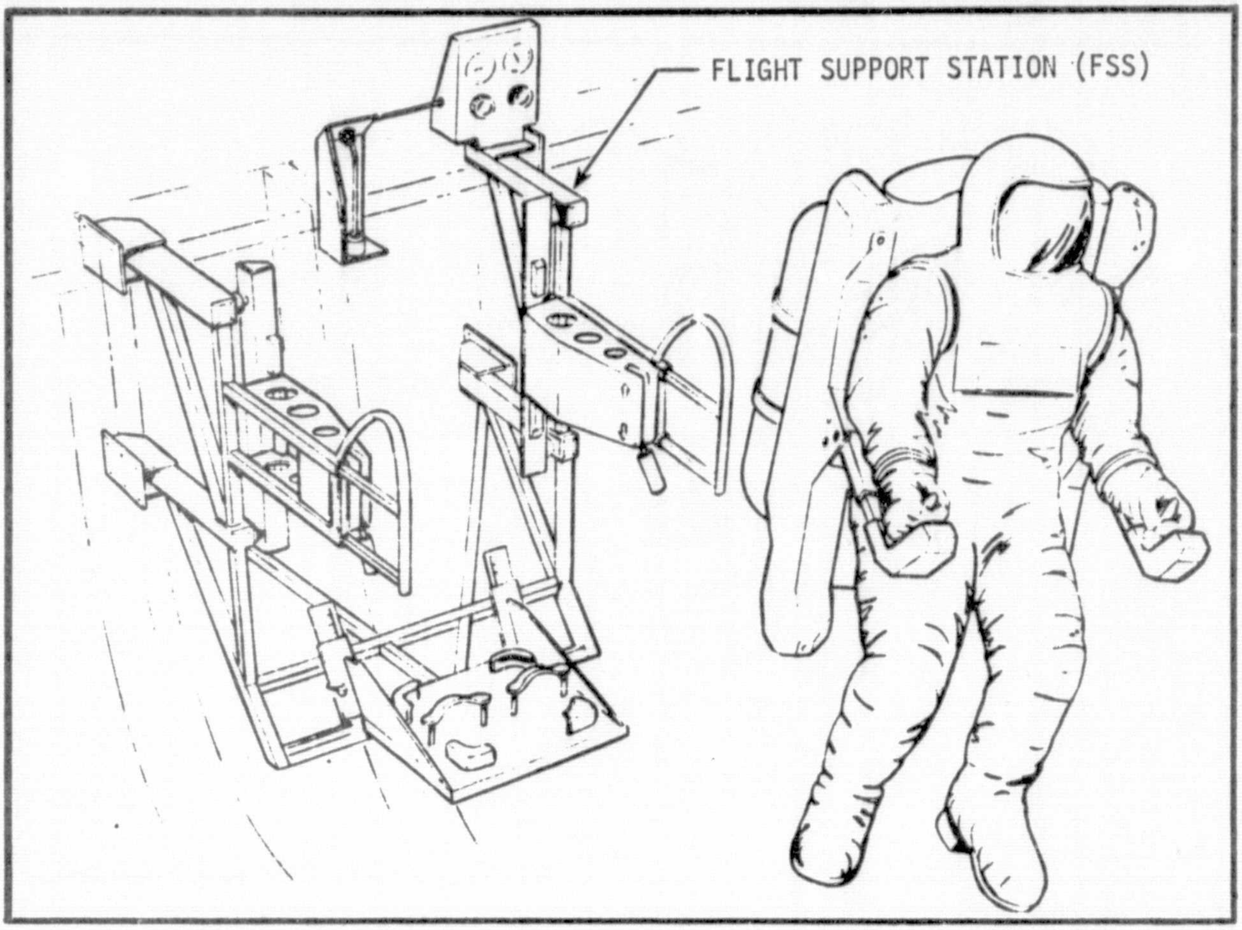


FIGURE 3.5-2: MMU Flight Support Station

The MMU interfaces directly with the EMU primary life support system assembly. Design features of the MMU-to-EMU latches provide fail-safe release of the EMU suited crewman when stowing the MMU in the payload bay. Provisions for mounting movie or TV cameras and various cargo items are incorporated into the MMU design. In the event the Orbiter payload bay doors cannot be opened, the MMU can be transferred through the Orbiter 101.6 cm. (40 in.) diameter side hatch for contingency operations.

3.5.2 EVA With MMU Capabilities

At the time of report preparation, the Space Shuttle MMU was in the preliminary design phase with operational units tentatively scheduled for late 1980.

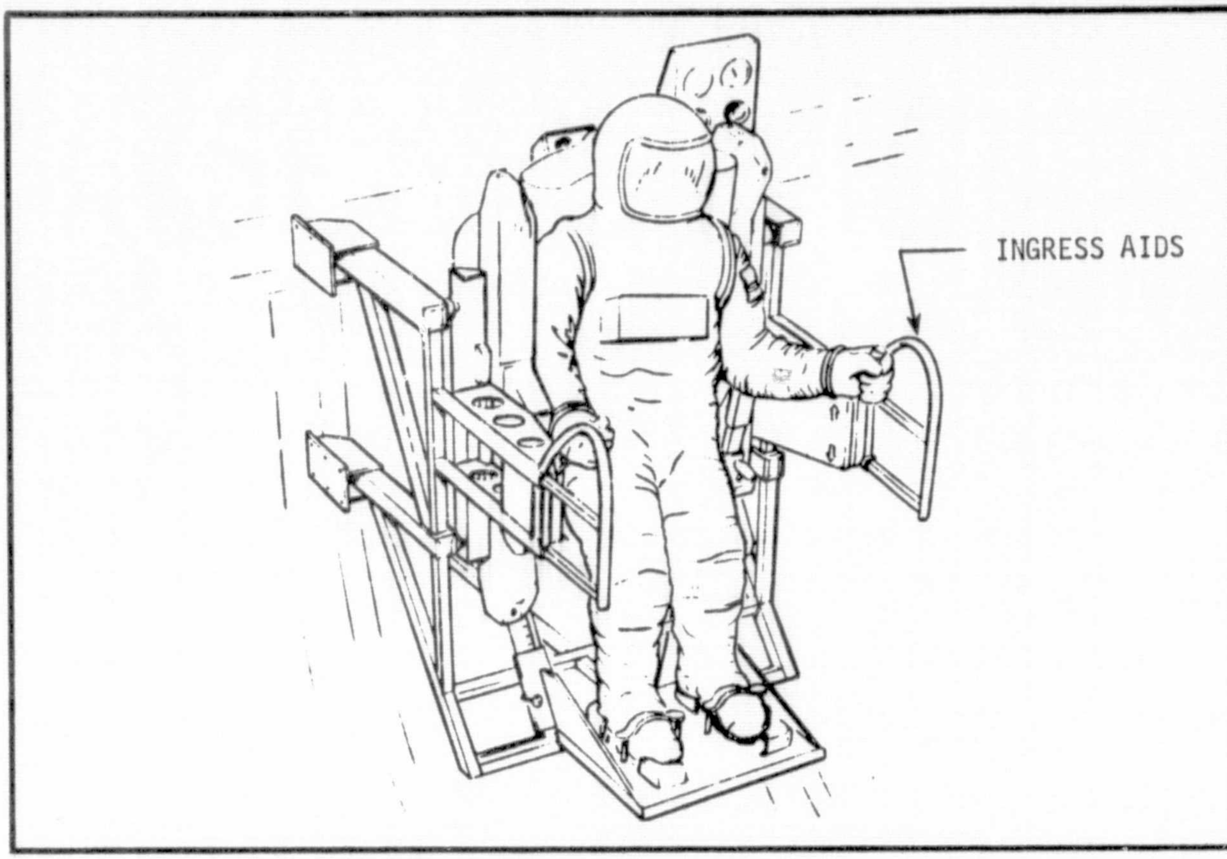


FIGURE 3.5-3: MMU Don/Doff Configuration (One-Man Don/Doff)

However, the Skylab Automatically Stabilized Maneuvering Unit (ASMU), a forerunner to MMU design, was evaluated inside the 6.7 m. (22 ft.) diameter Skylab Orbital Workshop. The ASMU (in Skylab Experiment M509) successfully demonstrated the capability for spacesuited crewmen to maneuver in zero-gravity with extreme precision. Five crewmen evaluated the ASMU in both shirtsleeve and suited modes for a total of 13.9 hours. Although not optimized relative to size and weight, the ASMU verified the capability to perform the following activities (Ref. 3.5.2):

- Point-to-point translation between worksites or free-flying vehicles
- Provide a "standoff" observation point
- Inspect and photograph Orbiter/satellite exterior surfaces

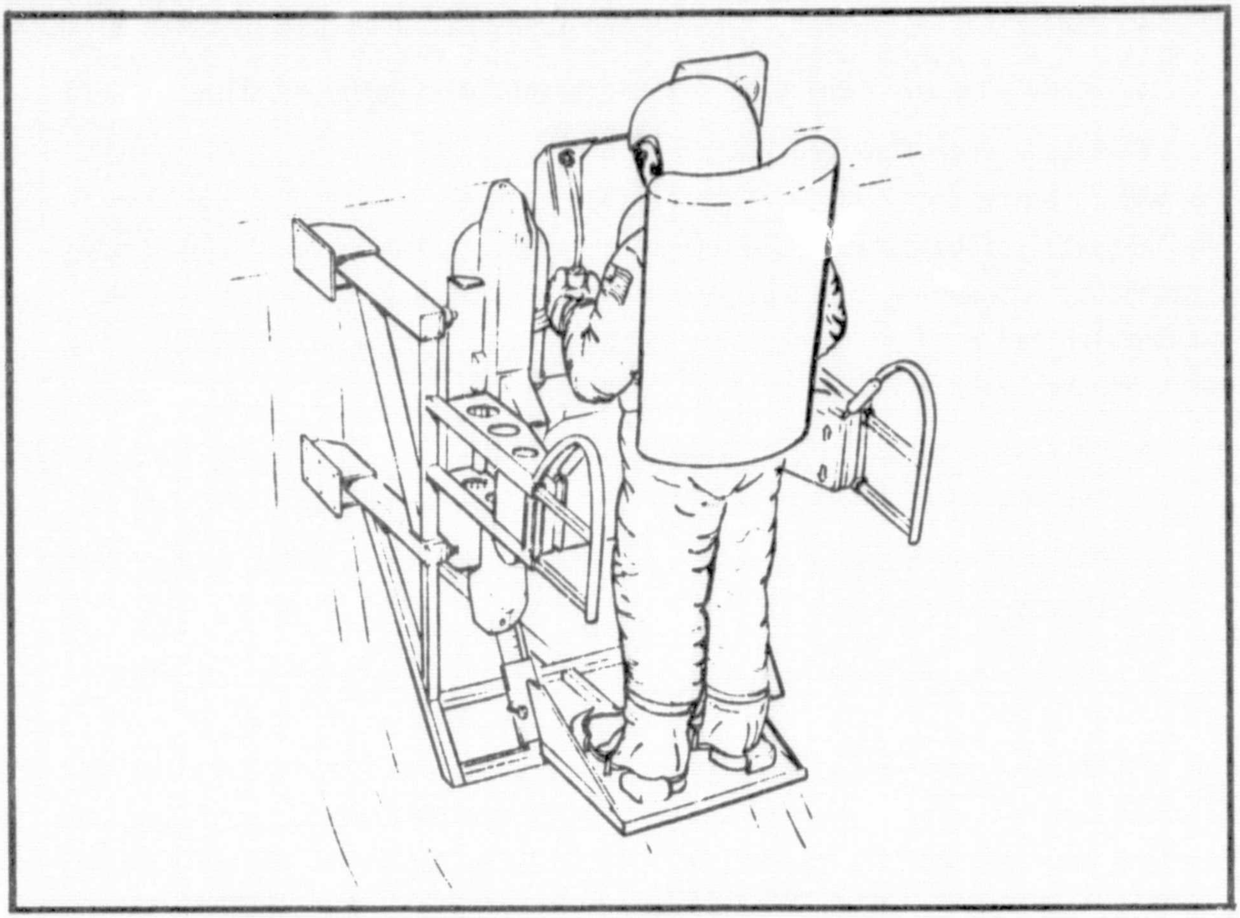


FIGURE 3.5-4: MMU On-Orbit Servicing (One-Man Servicing)

- Transport cargo items of approximately 100 kg. (220 lbs.) mass with dimensions of a spacesuited crewman
- Retrieve and replace experiment samples, film magazines and data packages
- Precision maneuvering and stationkeeping within ± 3 cm. (± 0.1 ft.) and ± 0.1 cm/sec (± 0.003 ft/sec)
- Perform installation, extraction, reconfiguration and cutting tasks
- Apply spray coatings (e.g., adhesive, ablative, protective) to vehicle surfaces
- Deploy and retract arrays, antennas and booms

- Deploy cables, wires, tethers and translation devices between vehicles
- Rendezvous with and duplicate spin rate of slowly rotating objects
- Rescue free-floating EVA crewmembers.

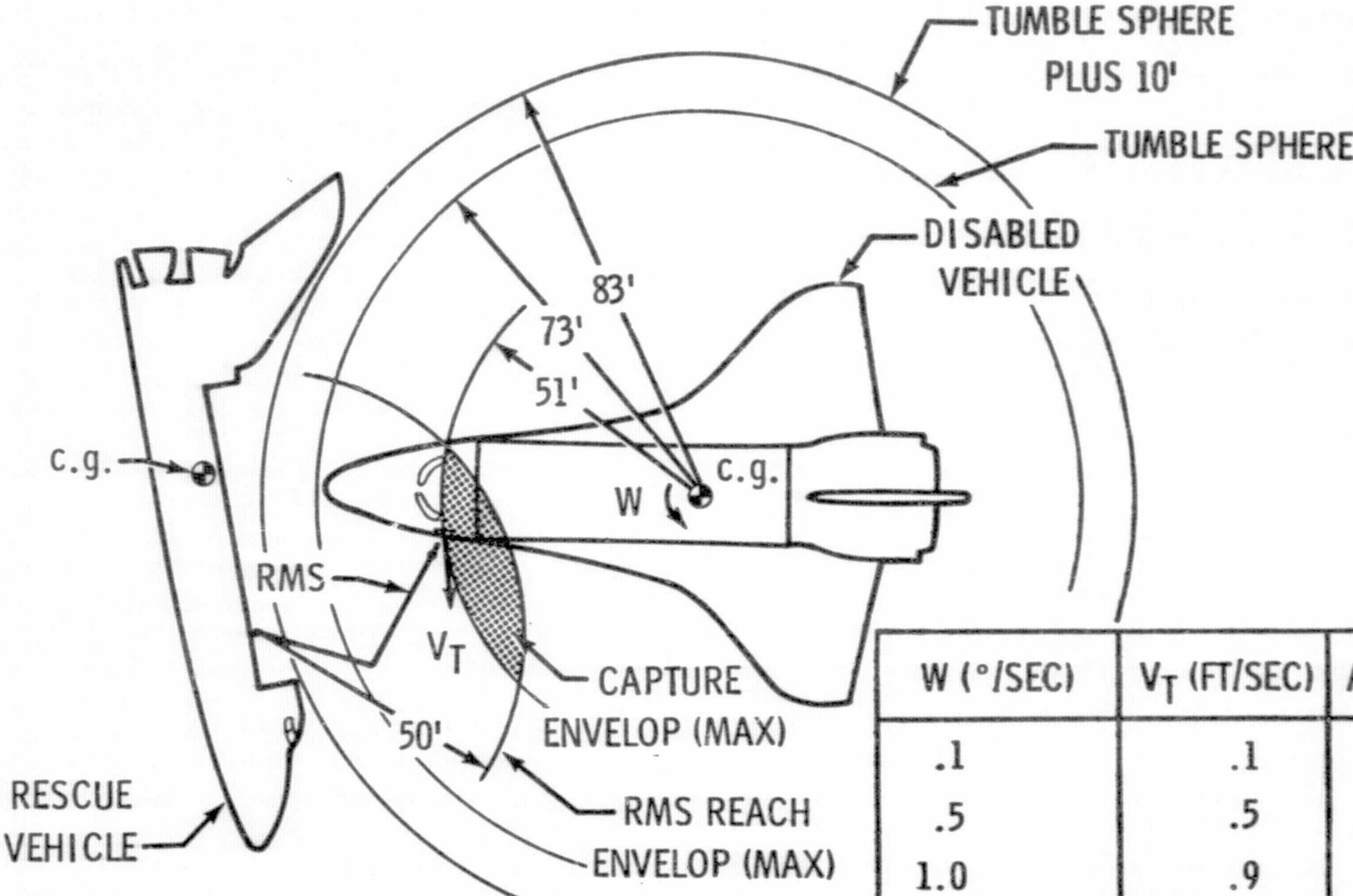
The MMU is being designed to allow similar task performance on the Shuttle. The initially proposed applications of the MMU are in the unscheduled and contingency categories for Orbiter and free-flying payload support. The unscheduled EVA with MMU operations considered within basic MMU capability early in the Shuttle flight program include:

- Flyaround inspection of the Orbiter and payload exteriors, especially the Orbiter Thermal Protection System for reentry status
- Malfunction assessment of vehicles and payloads including documentary TV and photographs
- Access to spacecraft/satellite areas requiring remedial repair.

The initial MMU contingency operations for Shuttle application involve rescue of crewmembers from a disabled, unstable Orbiter. Although the present rescue baseline does not require an MMU, if the disabled Orbiter's unstable attitude precludes RMS rescue or requires crewmember bailout, an MMU may provide the only means of effecting crew rescue (Figure 3.5-5).

EVA with MMU proposed applications for operational Shuttle flights beyond the 1980's range from simple spacecraft inspection tasks to capture, stabilization and retrieval of free-flying satellites. The ability of the MMU's to approach and rendezvous with contamination-sensitive payloads may have wide application on Shuttle payloads. The MMU contamination and perturbations to payloads would be much less than the Orbiter's 3872 N. (870 lbf.) thrust hypergolic reaction control engines.

Based on the results of Skylab maneuvering unit evaluations, the MMU is being designed to perform the following typical Orbiter and payload tasks (Ref. 3.5.3):



W (°/SEC)	V_T (FT/SEC)	A $\left(FT/SEC^2\right)$
.1	.1	.00
.5	.5	.00
1.0	.9	.02
3.0	2.7	.14
6.0 (1 RPM)	5.3	.56
12.0 (2 RPM)	10.7	2.24

• USE OF RMS FOR CREW TRANSFER

FIGURE 3.5-5: EVA Rescue from Unstable, Disabled Orbiter

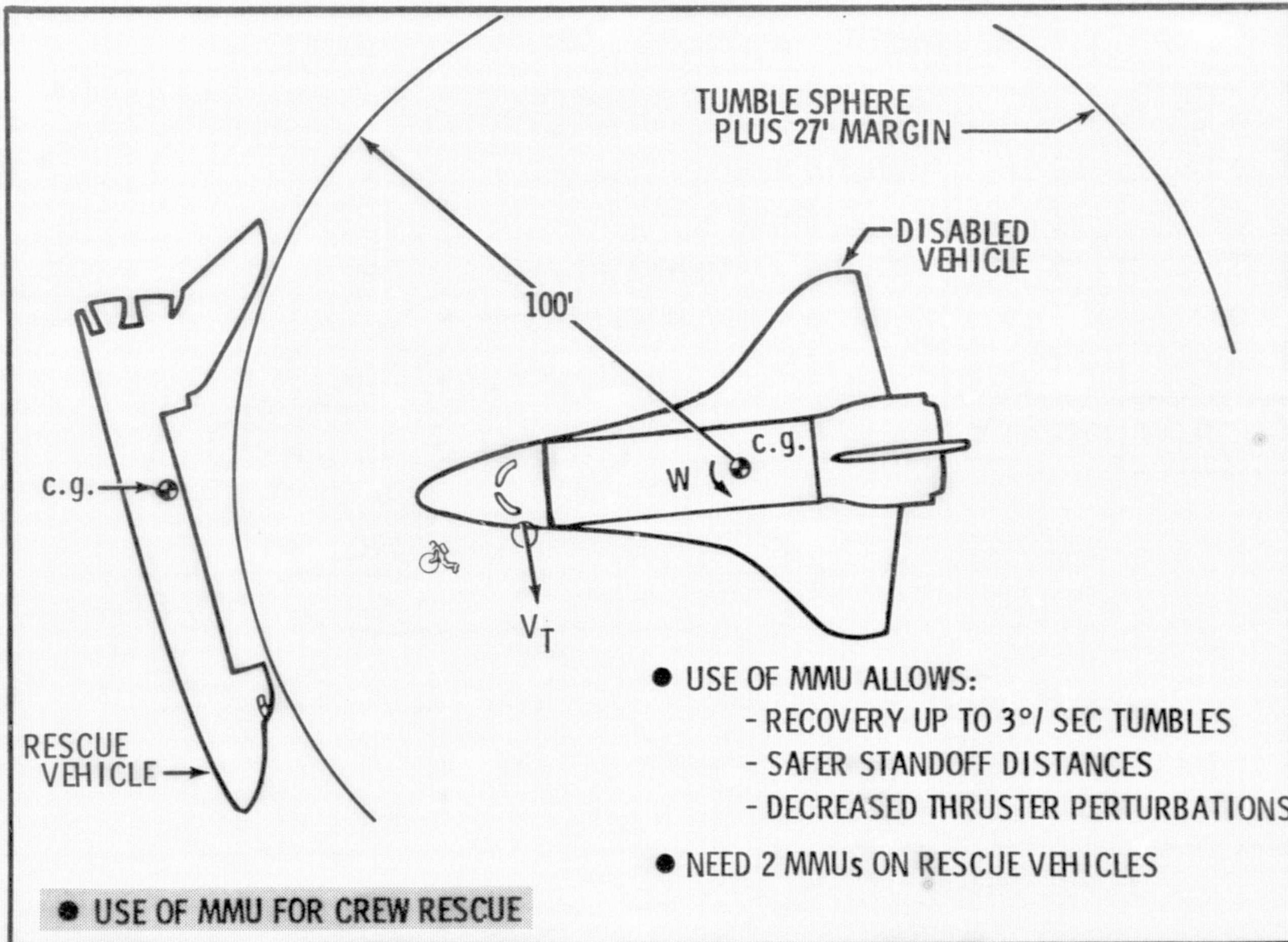


FIGURE 3.5-5: EVA Rescue from Unstable, Disabled Orbiter (Continued)

- Shuttle EVA Support Tasks
  - External inspection of the Orbiter (Figure 3.5-6)
  - Malfunction assessment
  - Remedial action (Figure 3.5-7)
  - Documentary photography/television
- Shuttle Payload Support Tasks
  - Payload deployment or retrieval
  - Adjustment of instruments
  - Retrieval and replacement of film, coatings, emulsions
  - Servicing free-flying payloads
  - Replacement of failed modules (Figure 3.5-8)
  - Cleaning sensors and lenses
  - Assembly of large structures (Figure 3.5-9)

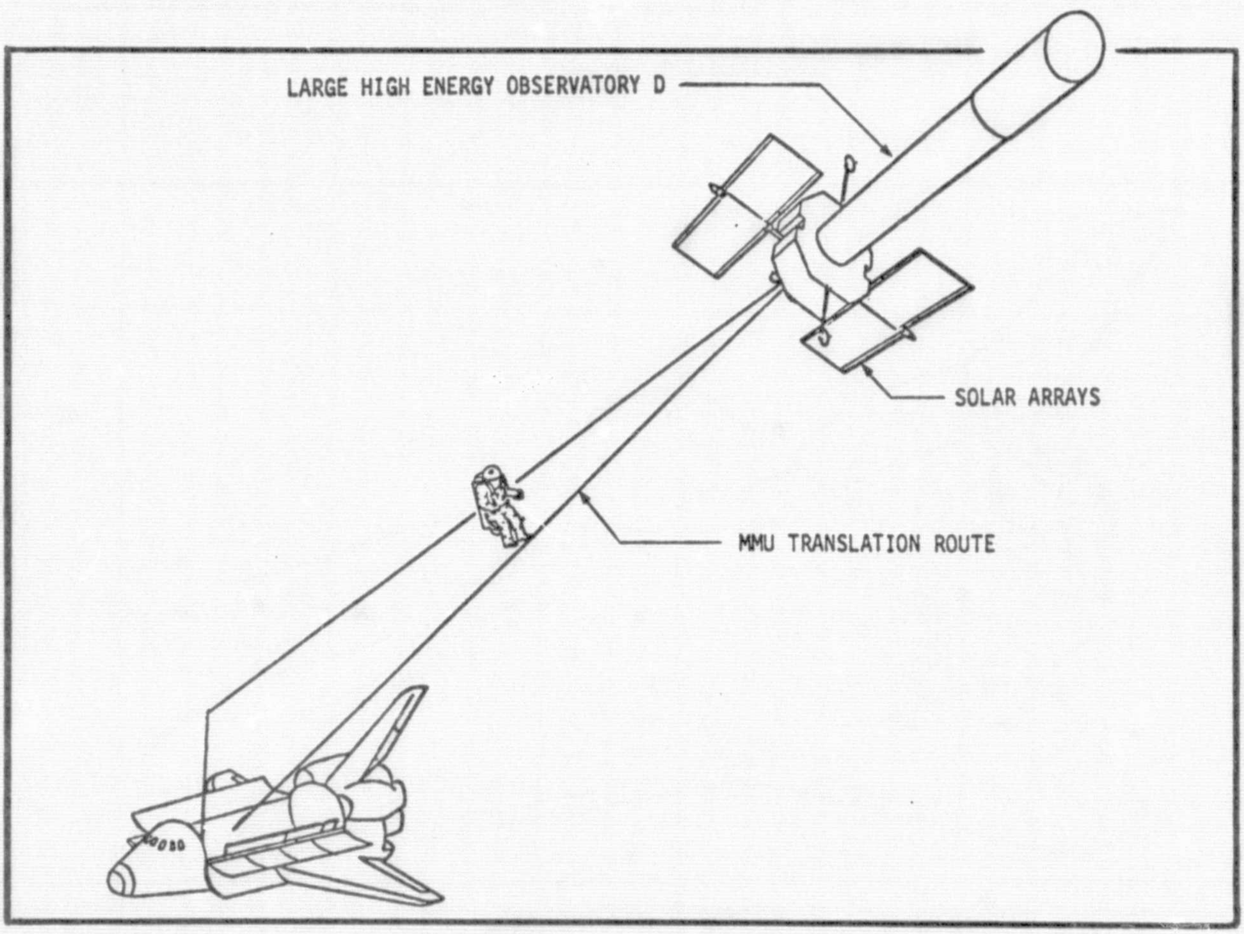


FIGURE 3.5-8: Replacement of Payload Modules by MMU Mode (Concept)

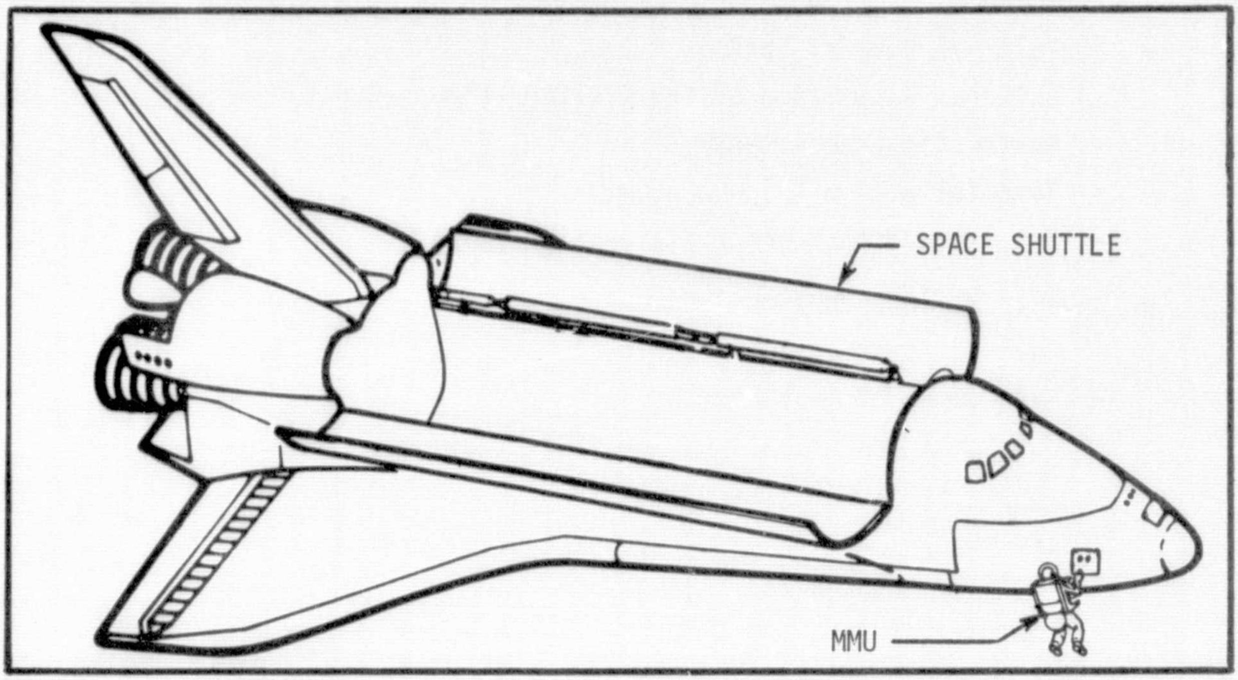


FIGURE 3.5-6: MMU Orbiter Inspection Operations Concept

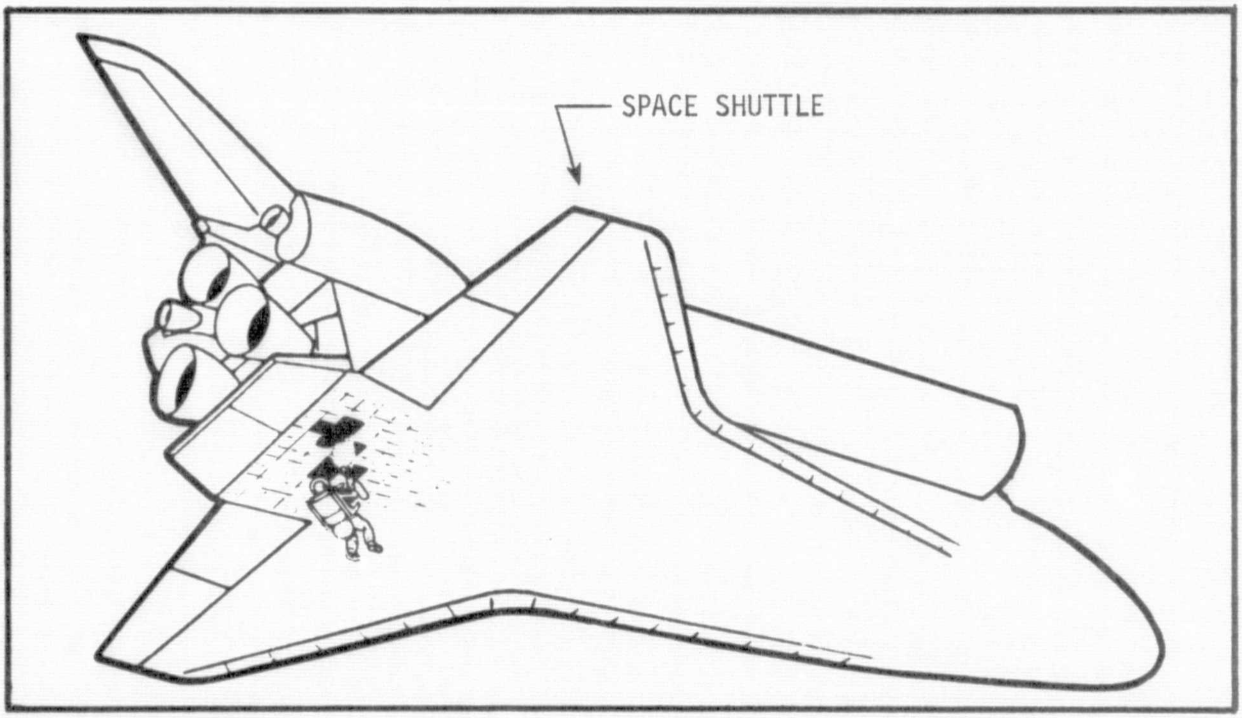


FIGURE 3.5-7: MMU Remedial Servicing of Thermal Protection System (Concept)

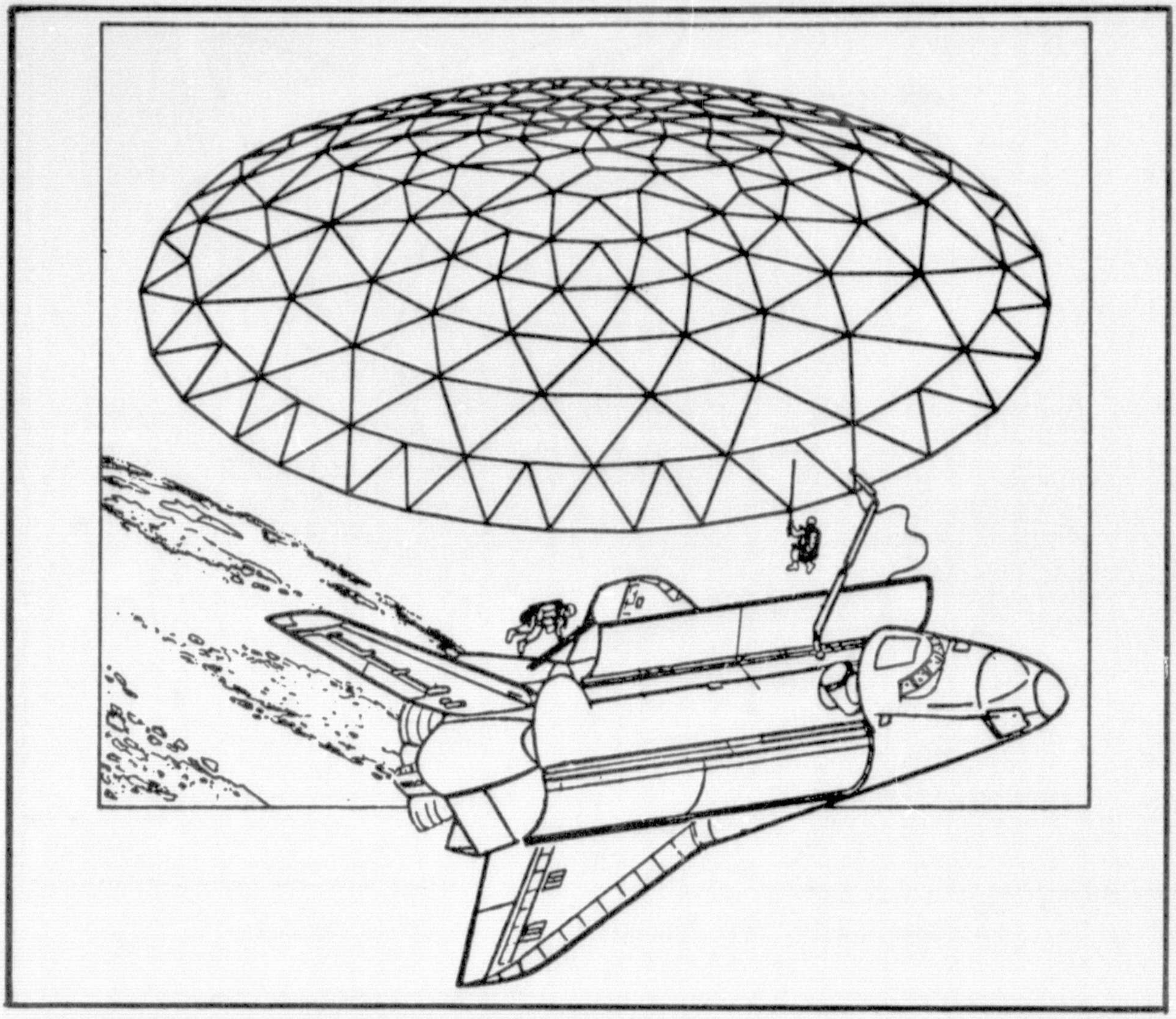


FIGURE 3.5-9: MMU Concept of Large Space Structure Assembly

- Routing of cables or lines between discontinuous points
- Application of spray coatings
- Removal of contamination protective covers
- Malfunction assessment
- Remedial action

• Crew Rescue Support Tasks
  - Enhance the transfer of crewmen and equipment in a rescue situation (Figure 3.5-10)

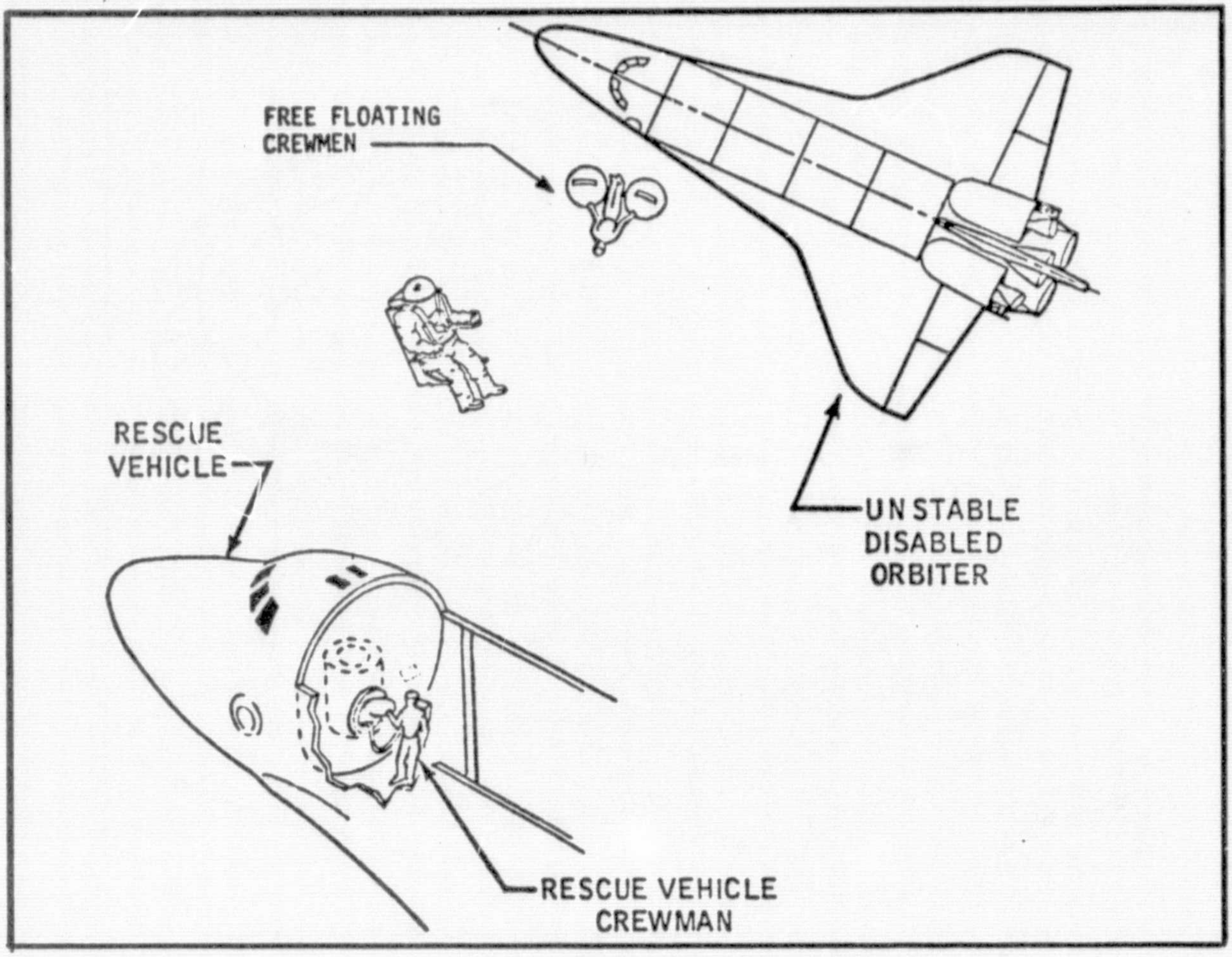


FIGURE 3.5-10: MMU Concept of EVA On-Orbit Rescue

Numerous EVA with MMU subtasks can be identified within the above task categories. The MMU utility in a supporting capacity to Shuttle EVA will become more apparent as Orbiter and payload designs mature.

3.5.3 EVA With MMU Limitations

The EVA with MMU operational mode is limited for certain task categories unless additional provisions and support hardware are part of the operational mode equipment. Applicable limitations are described below.

3.5.3.1 MMU Operational Range

The MMU is being designed for operation within the immediate vicinity of the

Orbiter: 100 m. (330 ft.). Contamination-sensitive payloads may require the Orbiter to maintain distances of up to 760 m. (2500 ft.) during operation. A consideration in MMU ancillary equipment design should include the required navigation and support gear to allow greater MMU travel distance.

3.5.3.2 MMU-to-Worksite Attachment

Only very small forces can be applied in the EVA with MMU mode while free-flying. Most payload tasks will require the MMU or crewman to be restrained at the worksite. Provisions for attaching the MMU or restraining the crewman (e.g., foot restraints, tether points, portable workstation) will be required.

SECTION 3.5 REFERENCES

3.5.1 Whitsett, Charles E. Status Review of the Manned Maneuvering Unit (MMU) Program, NASA-JSC presentation, August 18, 1975.

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3.5.3 Martin Marietta Corporation: Manned Maneuvering Unit System Design Specification, Contract No. NAS9-14593, MCR-75-398, October 10, 1975.